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Original Paper

Electronic Games for Facilitating Social Interaction Between Parents With Cancer and Their Children During Hospitalization: Interdisciplinary Game Development

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Abstract

Background: Most cancer treatments today take place in outpatient clinics; however, it might be necessary for some patients to be admitted to hospital departments due to severe side effects or complications. In such situations, support from family and social relations can be crucial for the patients' emotional well-being. Many young adolescents and children whose parents have cancer describe how they are not seen, heard, or listened to as the worried relatives they are. Within the intensive care unit, it has been recommended that early supportive interventions are tailored to include children of the intensive care patient; a similar approach might be relevant in the oncological setting. To our knowledge, no studies have explored how to involve young relatives who are visiting their parent at an oncological department. Recently, a framework for developing theory-driven, evidence-based serious games for health has been suggested. Such a process would include stakeholders from various disciplines, who only work toward one specific solution. However, it is possible that bringing together different disciplines, such as design, art, and health care, would allow a broader perspective, resulting in improved solutions.

Objective: This study aims to develop tools to enhance the social interaction between a parent with cancer and their child when the child visits the parent in the hospital.

Methods: In total, 4 groups of design students within the Visual Design program were tasked with developing games addressing the objective of strengthening relations in situ during treatment. To support their work, the applied methods included professional lectures, user studies, and visual communication (phase I); interviews with the relevant clinicians at the hospital (phase II), co-creative workshops with feedback (phase III), and evaluation sessions with selected populations (phase IV). The activities in the 4 phases were predefined. This modified user design had the child (aged 4-18 years) of a parent with cancer as its primary user.

Results: Overall, 4 different games were designed based on the same information. All games had the ability to make adults with cancer and their children interact on a common electronic platform with a joint goal. However, the interaction, theme, and graphical expression differed between the games, suggesting that this is a wide and fertile field to explore.

Conclusions: Playing a game can be an efficient way to create social interaction between a parent with cancer and a child or an adolescent, potentially improving the difficult social and psychological relations between them. The study showed that the development of serious games can be highly dependent on the designers involved and the processes used. This must be considered when a hospital aims to develop multiple games for different purposes.

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KEYWORDS

cancer patients; children; adolescents; social relation; emotional well-being; gamification; relatives; visual design; serious games

Introduction

Patients diagnosed with cancer often undergo aggressive oncological treatment mainly provided by outpatient clinics at hospitals [1]. The patients experience a wide range of changing symptoms that occur due to the cancer itself as well as side effects from the treatment [2]. Sometimes, there are complications, resulting in a potentially life-threatening situation for the patient, requiring admission to the hospital. The two main disadvantages of such situations are related. First, the patients may suffer due to being away from their family [3]. Second, patients find themselves in a distressing situation and are left alone with their concerns and worries. In these situations, patients benefit from receiving emotional and social support from their close relatives. Social support includes personal, informal advice, and can provide strength that helps individuals initiate and sustain self-management activities. Existing literature has identified a correlation between patients' perceived degree of social support and quality of life [4]. Further, children and adolescents with a parent with cancer have noted that they are not seen, heard, and listened to as the worried relative they are [5]. Few studies have explored the experiences of children and adolescents across a parent's illness trajectory; however, a recent meta-synthesis recommended early supportive interventions tailored to include the children of intensive care patients [6]. To our knowledge, no studies have explored how to include children who are visiting their parent at an oncological department. Still, there is a general acknowledgment that health care professionals need to reflect on how to approach children and young adolescents at the hospital when they are visiting a parent [5,7]. Gamification, serious gaming, and edutainment have the potential to establish enjoyable and motivating experiences when gaming elements are introduced in a nongaming context [8]. The notion of gamification and serious gaming is traditionally used to increase adherence to medication regimens, promote health education for patients, and offer apps for chronic disease management [9]. Video games and serious gaming have the ability to enchant and engage patients and their children in a different "world" and thus give them a collective short break from the otherwise rather serious context they are in together. We are not aware of other studies aimed at facilitating social and joyful interaction between a parent with cancer and their children through gamification during hospitalization in an oncological department. However, virtual emotional authenticity and feelings of empathy may be able to help patients with cancer frame the often traumatizing experiences in more positive terms [10]. The development of serious games for such purposes is, as in eHealth generally, based on scientific and design foundations [11]. However, the product developed for a given purpose might be dependent on the software provider, the processes, or the specific designer asked to address specific needs. By bringing together different disciplines and acknowledging the diversity in art and design, more solutions might be designed for the same purpose [12]. This study aims to develop tools to enhance social interaction between a parent with cancer and their children when the children visit the parent at the hospital.

Methods

Overview

This study is based on an interdisciplinary co-creation process with clinical oncology specialists from Copenhagen University Hospital (KP, HG, and HP), gaming and visual design experts from The Royal Danish Academy of Architecture, Design, and Conservation (TK, JK, and JJ), and second-year bachelor's degree students at the Academy. The study did not need ethical approval. For this study, over 3 months, 4 different groups of design students within the Visual Design program were tasked with developing games addressing the objectives of the field of design and focusing on strengthening relations in situ during treatment. This modified user-centered design had the child (aged 4-18 years) of a parent with cancer as its primary user. Target age groups were defined in the initial phases of the project based on statistical information from the department and the already established research focus of next of kin and young adults as relatives, as well as by established researchers from the field of developmental psychology and the complexity of the developed games [12]. We approached the target groups through the lens of media use, where a concrete game is part of the broader media ecology, meaning that material from a television series can cross into a video game, and a video game can cross into children's outdoor analog play [13]. This has a specificity that exceeds the level of detail offered by developmental psychology, and the guiding principle for design was therefore observations of the actual game and media use by children in the respective age brackets [13]. The activities in the 4 phases were structured and predefined.

Phase I

The clinical specialists presented the clinical settings and environment of the oncological department (eg, standard cancer disease and treatment trajectories) to the students, as well as the context of the study aim and ethical issues. The students signed a confidentiality agreement. Discussions on how to establish and strengthen social and joyful togetherness between the admitted parent with cancer and their children were facilitated. There was an underlying consideration of how to nurture the experience of social support that may play an important role in a multifaceted approach to preventing complicated grief among relatives. The hospital and its staff were defined as customers in the development process, and the field of developmental psychology was researched throughout the process [13].

Phase II

The students interviewed nurses (n=4) who were selected to be informers due to their extensive experiences with patients with cancer and their relatives.

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Phase III

Students listened to the story of a bereaved child from The Danish National Center for Grief. Students were given a lecture by a researcher with a special interest in and knowledge of children as relatives of parents with cancer [14]. Students could ask questions of and engage in discussions with both lecturers.

Phase IV

The students presented their initial prototypes and received feedback from the multidisciplinary team. Acceptability testing was performed in an external population; a class of healthy children from the same age group was used for this purpose. Adjustments were incorporated ahead of an official presentation at the hospital and visitors at the prototype exhibition were randomly included in the usability test. Hence, the prototypes were tested for usability using this small, selected population via surveys. Tests of the prototypes with hospitalized parents with cancer and their children were not performed due to ethical considerations.

Results

In phases I-III, the facts used for the design process were documented in written reports by the 4 working groups. Information from interdisciplinary stakeholders such as patients, nurses, research specialists, clinical oncological specialists, and gaming and visual design experts was included as a design foundation for all reports. In phase IV, 4 independent prototype games were developed (Table 1). Each game included an acceptance test using nontarget populations.

Table 1. Prototypes of the games.

Game title	Theme	Target age group (years)	Element of interaction	How the game aims to create social interaction	Number of players
Fun and Cozy Socks	Good mood gaming	15-18	Sample of social and interactive guessing minigame	Establishes a feel-good atmosphere with competition and laughs	2-3
The Witch	Magic team building game	4-8	Cooperative multiplayer game, book, and electronic game	Provides a fun and enjoyable activity that builds trust between the players	2
Kurt, the Hospital Cat	Augmented reality	6-12	The interactive experience of a real-world environment with a search for items in the physical surroundings	Adds information and meaning to the hospital surroundings	1 (includes the possibility of interacting with a parent in search for items)
Bloom	Growing a garden and bringing it to life	4-18	Customization/minigames	Makes the players feel good and is enjoyable. Shows that you care for a person by growing flowers and taking care of them.	1 player on a social platform

In general, the prototypes were highly accepted by age-equivalent testing groups. A usability test among random visitors at the parallel presentation of all 4 solutions included patients (n=6), health care professionals (n=10), and young adults (n=3). The survey results included good ratings for “interesting game,” “user friendly,” and “willingness to use” in a hospital setting. In general, all solutions were positively evaluated, reflecting a fundamental interest in playing games to experience joyful moments. However, the older population (aged >70 years) seemed to have reduced digital competencies and a lower willingness to use such games.

The prototypes (Figure 1) were tested on a small, selected population via a paper-based survey. Physical contact testing was not possible due to ethical concerns.

Figure 1. Front pages for game prototypes.



Discussion

Principal Findings

Based on the same information and evaluation, 4 different working groups skilled in visual design developed games with different themes and interactions, for different target age groups, to solve the same challenge. This study shows that gamification has the potential to solve newly revealed needs within health care, such as improving interactions between a parent with cancer and their child. This study suggests that several types of designs can solve the same problem, but also underscores that

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solutions are highly dependent on the software developer and designer. These factors should be considered when, for example, a hospital aims to develop multiple games for different purposes, or when the best game for a specific purpose is requested.

It has previously been described how patient and family involvement is valuable for health [15]; however, little is known about the involvement of children as relatives. In the adult setting, eHealth tools have been developed for adult relatives [16] to improve their psychological well-being, but not to improve their interactions with the patient. It is known that web-based tools and games can be used to improve adolescents' and young adults' adherence to vaccination programs and therapy [17,18]. It seems that eHealth tools can improve psychological outcomes [19]. It might be argued that the development of serious games for health should be based on a framework suggested by Verschueren et al [11]. However, to improve the quality of serious games for health, this study tries to encourage interdisciplinary cooperation between art and health science experts to elicit a greater number of suggestions of game-based solutions for the same purpose, followed by a selection of the best feasible solution for a specific need considering the different themes and graphic design elements of the developed games.

Limitations

A limitation of this study might be that the tools were developed by students; however, they were supervised by experts in gamification and evaluated and given continuous feedback during the process by user design and gamification experts. A modified concept of user-centered design was applied to this tool developing process, where experiences from one young relative and other stakeholders were the basis for the development. However, this one representative was used to represent a group of children and young relatives of patients with cancer.

All 4 working groups performed an acceptance test of their product in a nonhospital environment (eg, a day care facility or school). The usability test involved the parallel testing of all 4 tools in a hospital environment and included children/young people, patients/relatives, and hospital staff. None of these tests were performed with a larger group of children who are relatives of patients with cancer; thus, the generalizability of the findings must be further explored.

Conclusion

A game can be an efficient method for fostering social interaction between a parent with cancer and a child or an adolescent, and games likely have the power to improve the difficult social and psychological relations between parents and children in this context. When creating games for specific purposes such as this, it must be remembered that games designed based on the same assignment might use different themes and graphic design elements, indicating that the development of serious games may be highly dependent on the designer involved. The described games remain to be investigated more thoroughly regarding their feasibility and efficacy in the context of qualitative oncological research. If shown to be feasible, implementation among patients with cancer and their relatives will be carried out.

Acknowledgments

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Conflicts of Interest

None declared.

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Original Paper

Validation of a Portable Game Controller to Assess Peak Expiratory Flow Against Conventional Spirometry in Children: Cross-sectional Study

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Abstract

Background: International asthma guidelines recommend the monitoring of peak expiratory flow (PEF) as part of asthma self-management in children and adolescents who poorly perceive airflow obstruction, those with a history of severe exacerbations, or those who have difficulty controlling asthma. Measured with a peak flow meter, PEF represents a person's maximum speed of expiration and helps individuals to follow their disease evolution and, ultimately, to prevent asthma exacerbations. However, patient adherence to regular peak flow meter use is poor, particularly in pediatric populations. To address this, we developed an interactive tablet-based game with a portable game controller that can transduce a signal from the user's breath to generate a PEF value.

Objective: The purpose of this study was to evaluate the concordance between PEF values obtained with the game controller and various measures derived from conventional pulmonary function tests (ie, spirometry) and to synthesize the participants' feedback.

Methods: In this cross-sectional multicenter study, 158 children (aged 8-15 years old) with a diagnosis or suspicion of asthma performed spirometry and played the game in one of two hospital university centers. We evaluated the correlation between PEF measured by both the game controller and spirometry, forced expiratory volume at 1 second (FEV_1), and forced expiratory flow at 25%-75% of pulmonary volume (FEF_{25-75}), using Spearman correlation. A Bland-Altman plot was generated for comparison of PEF measured by the game controller against PEF measured by spirometry. A post-game user feedback questionnaire was administered and analyzed.

Results: The participants had a mean age of 10.9 (SD 2.5) years, 44% (71/158) were female, and 88% (139/158) were White. On average, the pulmonary function of the participants was normal, including FEV_1, PEF, and FEV_1/forced vital capacity (FVC). The PEF measured by the game controller was reproducible in 96.2% (152/158) of participants according to standardized criteria. The PEF measured by the game controller presented a good correlation with PEF measured by spirometry (r=0.83, P<.001), with FEV_1 (r=0.74, P<.001), and with FEF_{25-75} (r=0.65, P<.001). The PEF measured by the game controller presented an expected

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mean bias of –36.4 L/min as compared to PEF measured by spirometry. The participants' feedback was strongly positive, with 78.3% (123/157) reporting they would use the game if they had it at home.

Conclusions: The game controller we developed is an interactive tool appreciated by children with asthma, and the PEF values measured by the game controller are reproducible, with a good correlation to values measured by conventional spirometry. Future studies are necessary to evaluate the clinical impact this novel tool might have on asthma management and its potential use in an out-of-hospital setting.

(JMIR Serious Games 2021;9(1):e25052) doi:10.2196/25052

KEYWORDS

asthma; pediatrics; serious game; peak expiratory flow; pulmonary function test, adherence, self-management

Introduction

Asthma is a chronic pulmonary disorder that affects more than 339 million people globally [1]. It is the world's most prevalent chronic disease in children, affecting 7.5% of children in the US [2], and can have a significant impact on one's life. Indeed, asthma attacks result in 146,000 annual visits to emergency departments and are the primary cause for school absence [3]. Characterized by reversible airway narrowing and chronic inflammation, asthma is a heterogeneous disease that can present with diverse respiratory symptoms, which can be periodically exacerbated by personal triggers [4,5]. While recognition of asthma symptoms is key to managing and preventing asthma exacerbations, self-perception and self-reporting of symptoms by the affected individuals is often difficult and unreliable [6]. This is particularly problematic in children. As such, international guidelines [7-9] recommend self-monitoring of PEF in the asthmatic population starting at 5 years of age, more specifically in children and adolescents who poorly perceive airflow obstruction, those with a history of severe exacerbations, or those who have difficulty controlling asthma. While symptoms-based asthma action plans have been shown to be superior to peak flow–based plans, peak flow may be used as a complementary measure to monitor symptoms in self-management of asthma. In fact, studies [10-12] have effectively shown that daily measurement of PEF in children as a self-monitoring tool can increase adherence to medications and decrease asthma exacerbations in children with poor symptoms perception. Despite this evidence, there is a low adherence to PEF monitoring using current peak flow meters in the pediatric population, with a reported 15% adherence to the Mini Wright Peak Flow Meter in children only 3 weeks after initial use [13]. Some of the identified barriers to PEF monitoring are the self-perception that one's asthma is well-controlled, the perceived burden of taking frequent measurements with seemingly low direct benefit to one's general health, and the financial barriers to purchasing a peak flow meter, with the cost ranging from 20-50 Canadian dollars per device (US $15.73-$39.33) [14]. This issue of low adherence to PEF monitoring in pediatric asthma needs to be addressed in order to engage and empower children early in healthy management of their chronic illness, improve their ability to perceive symptoms, and potentially decrease exacerbations.

Serious games, defined as games with a primary purpose other than pure entertainment [15], can be a means to increase adherence to treatments or therapies in chronic diseases and have been associated with positive health outcomes [16-18]. Serious games may be used to actively engage patients in their health management in a playful setting and are of particular use to children, given the gaming approach. Although several serious games have addressed the goal of knowledge acquisition in asthma [19], none has yet suggested a serious game approach to self-monitoring of asthma symptoms, including the measurement of PEF. Importantly, airflow measurements taken through serious games need to be validated against standard measures before the games can be implemented clinically.

In this study, we evaluated the validity of an airflow-based game controller paired with the *TikiFlow* game for portable electronic devices to monitor PEF in children with asthma using conventional spirometry as the comparison standard. We evaluated the concordance between PEF measurements obtained with the game controller and several spirometry measurements, and the reproducibility of PEF measured by the game controller without coaching. Furthermore, we assessed the participants' feedback both quantitatively and qualitatively to guide the continuous development of the game.

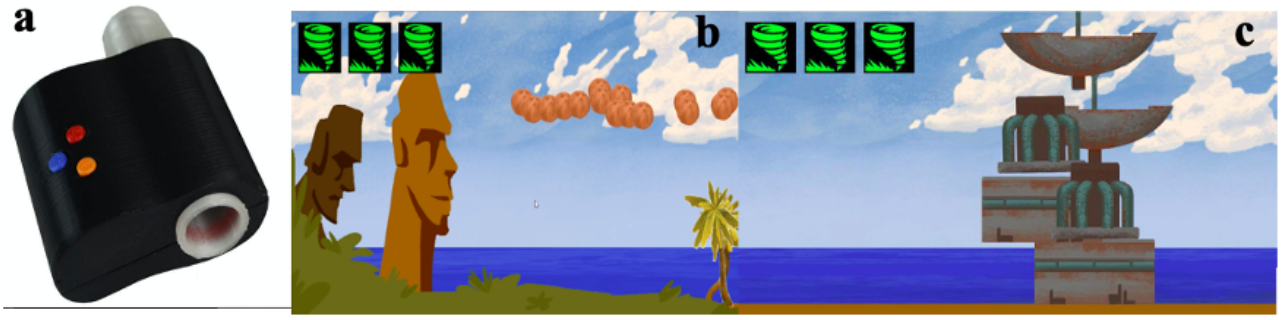
Methods

Game Controller and Game Design

We designed a 3D-printed game controller to transduce the user's breath into a digital signal and to meet the calibration standards of the Omron PF9940 peak flow meter. The game controller uses Bluetooth to connect to a portable electronic device and allows control of the *TikiFlow* game by the means of airflow through the game controller (Figure 1). The *TikiFlow* game challenges the participant to exert a forceful expiration in order to propel plant seeds, trigger a rainfall, and repopulate an island destroyed by pollution. PEF results measured by the game controller appear at the end of the game. The game can be previewed online [20].

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Figure 1. Representation of the game controller and the TikiFlow game. Children forcefully exhale in the mouthpiece of the game controller (a) to propel plant seeds, water them, and repopulate Tiki island with up to 5 attempts in the Tikiflow tablet-based game (b,c). The peak expiratory flow results appear at the end of the game. Images are copyrighted to breathinggames.net.



Design of the Study

We conducted a cross-sectional study on children who presented to the pulmonary function test laboratory of two pediatric university health centers in Quebec, Canada (Centre Hospitalier Universitaire Sainte-Justine and Centre Hospitalier Universitaire de Québec – Université Laval) over a 3-week period in November 2019. The respective institutional research ethics board approved this study (Centre Hospitalier Universitaire Sainte-Justine #MP-21-2020-2310, Centre Hospitalier Universitaire de Québec-Université Laval #MEO-21-2020-4711 and Concordia University #30011659).

Study Population

We included children aged 8-15 years old with a diagnosis of asthma or a suspicion of asthma presenting to pulmonary function test laboratory for a spirometry, with or without bronchodilator reversibility testing, at their physician's request. We excluded children with cystic fibrosis, bronchopulmonary dysplasia, and other conditions where the indication for pulmonary function test was unrelated to asthma (eg, follow-up of oncology patients or esophageal atresia). We also excluded children who were unable to cooperate for either conventional spirometry or assessment via the game controller according to American Thoracic Society guidelines. We identified eligible participants through the pulmonary function test laboratory database of both pediatric university health centers.

Measurements

We asked eligible and consenting participants to play *TikiFlow* with the game controller without coaching within 10 minutes of their conventional spirometry. Specifically, participants were given a brief overview of the game and its purpose and were asked to play on their own without instructions to exert more forceful exhalations or to increase the effort of breathing. Following the game, they also filled out a self-reported general health questionnaire and a satisfaction questionnaire.

Conventional spirometry measurements were obtained from a Jaeger MasterScope spirometer (Cardinal Health, Dublin, OH), using the Global Lung Initiative 2012 reference values [21] and interpreted according to American Thoracic Society guidelines [22]. Specifically, we retained the forced expiratory volume at 1 second (FEV_1), the forced expiratory flow at 25%-75% of pulmonary volume (FEF_{25-75}), and the forced vital capacity values from the participants' best curve, and the highest PEF value (PEF measured by spirometry). For PEF measured by spirometry, we evaluated the reproducibility of the spirometry in accordance with the American Thoracic Society guidelines, defined as the 2 highest values falling within 40L/min of each other [22]. For PEF measured by the game controller, we established a minimum of 3 reproducible forced exhalations as necessary, of which 2 must meet the American Thoracic Society reproducibility criteria, in order to end the game. The game was stopped if reproducibility could not be achieved after 5 exhalations. If the child was prescribed a reversibility testing with bronchodilators, which consists of repeating the spirometry 15 minutes following the administration of the bronchodilator salbutamol, we repeated the PEF game controller measurements following the post-bronchodilator spirometry. We collected the participant's appreciation of the game through a 5-question Likert-scale questionnaire and narrative feedback.

Statistical Analysis

We portrayed a descriptive analysis of the participants' baseline health and demographics based on the results of the self-reported questionnaire. A Bland-Altman plot was used to compare the game controller method to that of conventional spirometry and to evaluate the concordance of both methods to measure PEF. We calculated the spearman correlation between PEF measured by the game controller and by conventional spirometry measures. Statistical significance was set at $P<.05$. Analyses were performed with R software, version 3.5.0 [23]. Participant's appreciation of the game was evaluated quantitatively based on the satisfaction questionnaire administered and results were plotted in a bar graph.

Results

Population

We identified 337 children aged 8-15 years old presenting to both centers for a spirometry, with or without bronchodilator reversibility testing, 187 of whom were eligible based on inclusion criteria. We included 158 participants, as 9 were unable to perform spirometry and 20 refused to take part in the study, mostly due to time constraints (see Multimedia Appendix 1).

Participants had a mean age of 10.9 (SD 2.5) years (Table 1), and most were male (88/158, 55.7%), a proportion that reflects the sex distribution in pediatric asthma in the general population [24]. The majority were White (139/158, 88.0%). Up to 68%

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(108/158) of participants presented an atopic profile, defined as also having eczema or food or environmental allergies. The characteristics of participants were similar between both centers (see Multimedia Appendix 2).

Almost all participants (156/158, 98.7%) performed a reproducible spirometry. On average, the baseline lung function of participants was normal, with a mean percent predicted value of 103.7% (SD 11.7%) for forced vital capacity, 99.6% (SD 13.2%) for FEV_1, and 86.2% (SD 25.5%) for FEF_{25-75}. However, varying degrees of airway obstruction are represented in our participants as demonstrated by the range of percent predicted values and z scores (Table 2; see Multimedia Appendix 3).

Table 1. Selected baseline characteristics of participants (n=158).

Characteristic	Value
Age, mean years (SD)	10.9 (2.5)
Male, n (%)	88 (55.7)
BMI percentile, median (IQR)	49 (33.3-90.8)
Ethnicity, n (%)	
White	139 (88.0)
Black	11 (6.8)
Other	8 (5.1)
Diagnosis of asthma, n (%)	131 (82.9)
Age at diagnosis, mean years (SD)	4.2 (3.2)
Daily controller therapy, n (%)	133 (84.2)
ICS[a] only	58 (36.7)
ICS-LABA[b]	33 (20.9)
ICS-LTRA[c]	11 (7.0)
ICS-LABA-LTRA[d]	27 (17.1)
LTRA[e] only	4 (2.5)
Eczema, n (%)	45 (28.5)
Food allergy, n (%)	38 (24.1)

[a]ICS: inhaled corticosteroids.

[b]ICS-LABA: inhaled corticosteroids and long acting beta-agonist.

[c]ICS-LTRA: inhaled corticosteroids and leukotriene receptor antagonist.

[d]ICS-LABA-LTRA: inhaled corticosteroids, long acting beta-agonist and leukotriene receptor antagonist.

[e]LTRA: leukotriene receptor antagonist.

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Table 2. Baseline lung function assessed by conventional spirometry (n=158).

Function	Value
FVC[a]	
% predicted, mean (SD)	103.7 (11.7)
% predicted, range	66.5 to 142.9
z score, mean (SD)	0.3 (1.0)
z score, range	–3.0 to 3.5
FEV_1[b]	
% predicted, mean (SD)	99.6 (13.2)
% predicted, range	59.3 to 130.2
z score, mean (SD)	0.0 (1.1)
z score, range	–3.4 to 2.3
FEF_{25-75}[c]	
% predicted, mean (SD)	86.2 (25.5)
% predicted, range	20.8 to 184.8
z score, mean (SD)	–0.7 (1.2)
z score, range	–4.1 to 3.6
FEV_1/FVC[d], mean (SD)	83.6 (6.8)
PEF_{spiro}[e] (L/min), median percentile (IQR)	266.7 (230.1-336.9)

[a]FVC: forced vital capacity.

[b]FEV_1: forced expiratory volume in 1 second.

[c]FEF_{25-75}: forced expiratory flow at 25%-75% of the pulmonary volume.

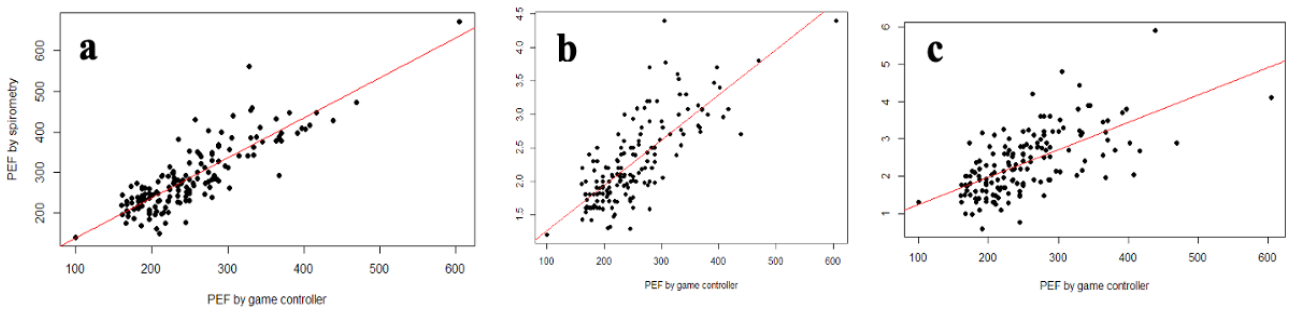
[d]FEV_1/FVC: forced expiratory volume in 1 second/forced vital capacity.

[e]PEF_{spiro}: PEF measured by spirometry.

Comparison of the Game Controller and Conventional Spirometry

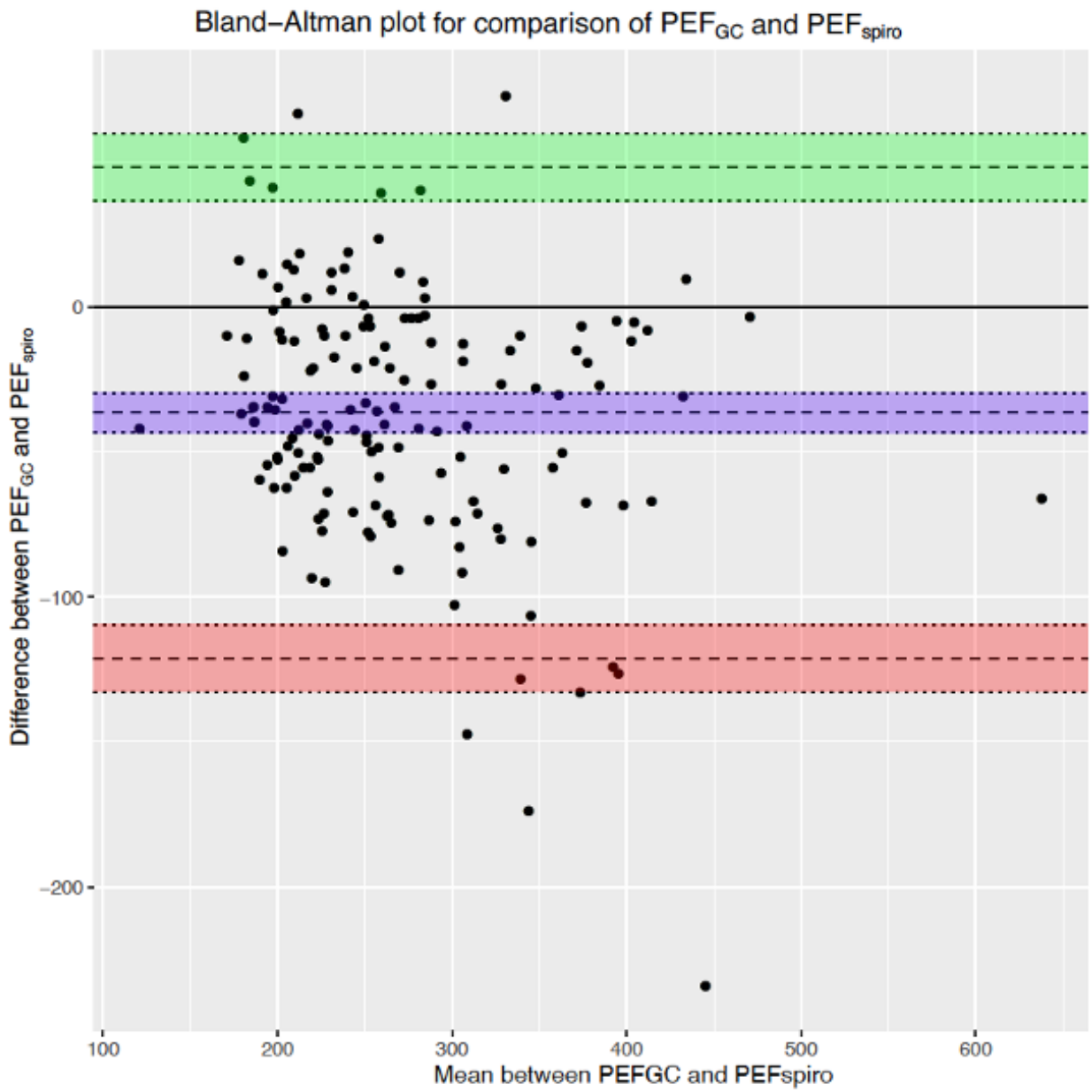
Despite the lack of coaching, 96.2% (152/158) of PEF values measured by the game controller were reproducible. Spearman correlations indicated that PEF measured by the game controller presented a good correlation with PEF measured by spirometry (r=0.83, P<.001), with FEV_1 (r=0.74, P<.001), and with FEF_{25-75} (r=0.65, P<.001) (Figure 2). The Bland-Altman plot showed that the PEF measured by the game controller presented a mean bias of –36.4 L/min (95% CI –43.2 to 29.6) compared to PEF measured by spirometry. The 95% limits of agreement, defined as the values within which 95% of differences between the two measurement methods lay, were –121.0 and 48.3 L/min (Figure 3). We identified 5 outliers, whose exclusion in a sensitivity analysis did not result in significant change in the concordance or correlation measures.

Figure 2. Correlation between PEFGC and selected conventional spirometry measurements. PEFGC shows good correlation with PEFspiro (a; r=0.83, P<.001), FEV_1 (b; r=0.74, P<.001) and FEF_{25-75} (c; $_{25-75}$=0.65, P<.001). PEFGC: peak expiratory flow measured by the game controller. PEFspiro: peak expiratory flow measured by conventional spirometry. FEV_1: forced expiratory volume in 1 second. FEF_{25-75}: forced expiratory flow at 25%-75% pulmonary volume.



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Figure 3. Bland-Altman plot comparing the game controller and conventional spirometry for PEF measurements. The game controller presents a mean bias of –36.4 L/min (blue; 95% CI –43.2 to –29.6) with a 95% upper limit of agreement of 48.3 (green; 95% CI 36.6 to 60.0) and a 95% lower limit of agreement of –121.0 (red; 95% CI –132.7 to –109.4) when compared to conventional spirometry. PEF: peak expiratory flow. PEF*GC*: peak expiratory flow measured by the game controller. PEF*spiro*: peak expiratory flow measured by conventional spirometry.



Of the 84 participants who underwent a spirometry pre- and post-bronchodilator administration, 7 were considered to have reversible airway obstruction as defined by a change in FEV_1 of ≥12% post-bronchodilator [25]. Using the game controller, 4 of those 7 participants were considered to have reversible obstruction as defined by a change in PEF measured by the game controller of ≥15%[26]. Based on these limited numbers, we could not reliably assess the responsiveness of PEF measured by the game controller to bronchodilator as compared to conventional spirometry.

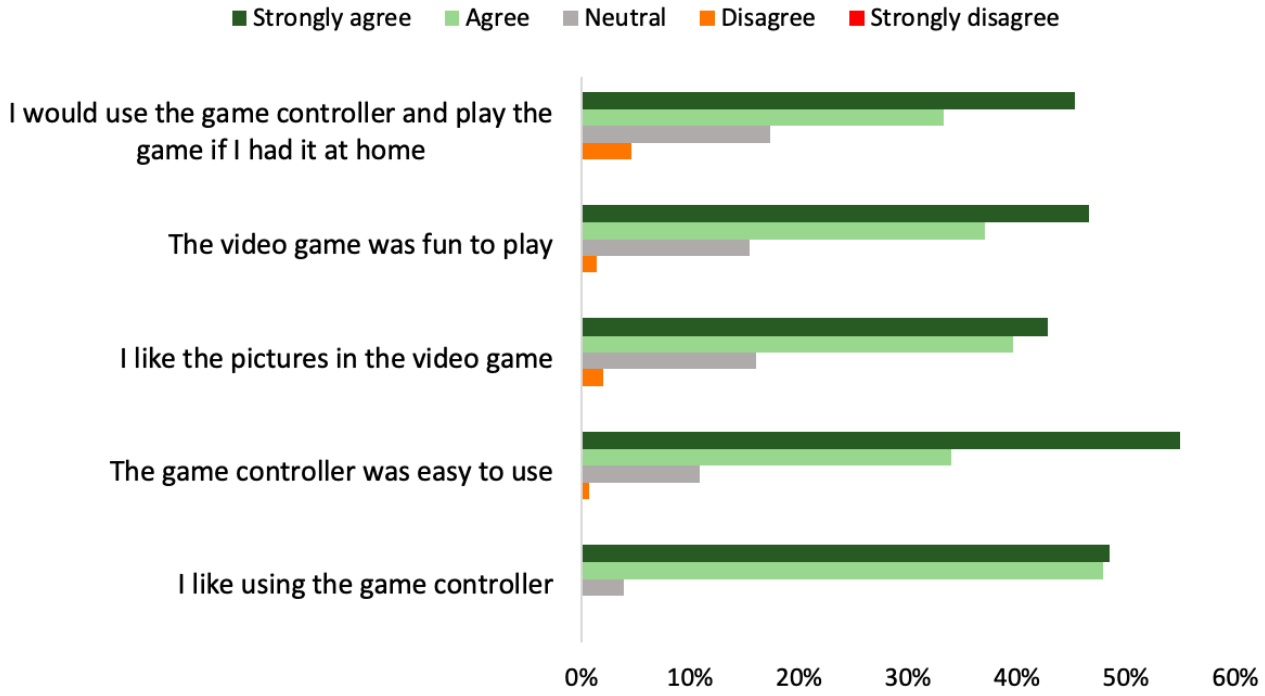
Appreciation Feedback of the Game Controller

Overall, users highly appreciated the game (Figure 4). No participant reported “Strongly disagree” to any of the 5 statements, and 78.3% (123/157) of participants reported they would use the game controller and play the game if they had it at home. 107 participants provided positive narrative feedback from which we noted that the main positive aspects of the game were the game concept (n=31), its educational aspect coupled with its entertaining aspect (n=14), and the ease of use of the game controller (n=25). Amongst the 28 youngest participants, aged 8-11 years old, who provided feedback on areas of improvement, the most recurrent comment was the desire for a longer duration to the game.

Of the 21 participants that gave negative narrative feedback, we noted the older users (aged 12-15 years) sometimes felt that the game content was intended for a younger population (n=6).

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Figure 4. Game appreciation as reported by the participants.



Discussion

Principal Findings

This study shows that the PEF measurements obtained through our game controller present a good correlation with conventional spirometry measurements and have a high reproducibility. Additionally, the participants reported overall strongly positive feedback on the game controller and the game, with 78.3% (123/157) reporting that they would play the game if they had it at home. These findings suggest that our game and controller could provide an objective measure of airway obstruction and that its use in an out-of-hospital setting could be explored.

PEF self-monitoring has been shown to reduce asthma exacerbations through the development of asthma awareness and control [10–12]. However, despite the international asthma guidelines recommendations for its adoption in poor symptoms perceivers and those with difficult to control asthma, few physicians educate and recommend PEF monitoring to their patients [27,28]. Two of the reasons for clinicians' low advocacy for peak flow meter use are the wide intraindividual variability in PEF values [29] and the low adherence to their use, particularly in pediatric patients with asthma.

Specifically, peak flow meters do not seem to consistently report PEF values that correlate with conventional spirometry, and a different measurement bias is associated with each peak flow meter [30,31]. Our game controller underestimated PEF measured by spirometry by 36.4 L/min, which is comparable to other peak flow meters [31-33]. This bias is expected as differing breathing techniques are used for PEF (child breathes out forcefully without coaching) and spirometry (child breathes out forcefully and completely with coaching) [31]. Reassuringly, our findings suggest a good correlation between PEF measured by the game controller and various spirometry measures across different degrees of baseline airway obstruction, suggesting that PEF measured by the game controller could be used as a surrogate to monitor trends in lung function. Furthermore, game controller measures were reproducible in 96.2% (152/158) of participants despite the lack of coaching, likely facilitated by the intuitiveness of the game narrative and mechanics. This finding suggests that PEF self-monitoring with our game controller would be feasible in a nonclinical environment without the supervision of a health care professional. Although we are not advocating for peak flow to replace symptoms-based asthma action plans, we believe that the addition of this objective measure in select patients can help with asthma control. This feature could have potentially significant benefits, namely by reducing barriers to health care access and reducing costs and transportations, all of which need to be further studied.

One suggested approach to increase adherence to medical treatments and to engage and empower the population in management of diseases is the use of serious games. Serious games have found their utility in different disciplines of medicine, whether to distract patients from a painful procedure, to engage adolescents in psychotherapies, or to educate patients on complex medical topics. Importantly, studies report a high adherence of serious games whether at home or in clinical settings [17-19]. Only 5 of 187 (2.7%) eligible children refused to participate due to a lack of interest, suggesting that *TikiFlow* appealed to the vast majority of children (see Multimedia Appendix 1). Additionally, more than 75% of the participants reported that they enjoyed the game (150/156), that it was fun to play (131/157), easy to use (139/157), and that they would use it at home (123/157). These findings were independent of age or sex.

Another approach to increase adherence specifically to PEF monitoring in asthma is the automatic generation of diaries as opposed to the traditional handwritten personal diaries of PEF

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measures. This approach decreases the effort required by the user and reduces the risk of false data generation. It also offers the possibility to depict measures graphically over time to identify trends. A recent study in the United Kingdom [34] suggests smartphone self-generated PEF diaries alone increase compliance with up to 32% of adults taking at least one PEF measurement daily for 3 months after the initiation of the study and 28% after 6 months. Our game takes advantage of this approach and integrates an automatically generated diary of PEF measures.

Serious games may be particularly beneficial among children with chronic conditions, where they were found to improve knowledge level and self-management [18]. The role of serious games in asthma self-management has been little explored. Asthma-related serious games, to date, have focused heavily on asthma education, and while they seem to improve knowledge transfer, they have been found to have little to no effect on behavior modification [19]. The novelty in our game, *TikiFlow*, is the use of a game controller with which the child uses their breath to control the game, bringing the focus to the play, rather than education alone. The acquisition of good asthma self-care habits early in childhood and adolescence may translate into long-lasting benefits in adulthood [35].

One notable strength of our game is its accessibility. Asthma is a global disease and the development of innovative tools to help patients and their families in their asthma management must be accessible to individuals in low- and middle-income countries. Smartphones and tablets represent ideal mediums to this end, as 66% of the world's population has access to such a device [36]. Our game and game controller are open source and our controller is 3D-printed, which makes it easy to reproduce at low cost and with minimal equipment, reducing access barriers. Furthermore, its small size and its portable format makes it easy to carry and incorporate in daily activities and, importantly, easy to disinfect.

There are several limitations to this study. First, our study does not include children aged 5-8 years old despite the international asthma guidelines recommending PEF monitoring in children aged ≥5 years old [8,37]. Our decision was to limit the confounders of poor effort and lack of cooperation in young children in the assessment of the game controller's validity. Further studies are necessary to evaluate the feasibility of PEF game controller measurements in this age group. Second, our study was conducted in tertiary care centers with a relatively healthy population with average normal functions at baseline. Thus, our results cannot be generalized to individuals with lower lung function or to those who are in acute exacerbations. Third, all game controller measurements were done systematically after conventional spirometry. Therefore, it is possible that fatigue contributed to skewing the game controller's measurements to lower values in our study. Participants were given instructions for the conventional spirometry prior to the game, which may have motivated a better effort on the game controller than could be expected with home measurements. However, we explicitly did not give instructions for the use of the game in order to reproduce the home environment as much as possible. Because we only had a few participants with documented reversibility to bronchodilator, we were not able to evaluate the responsiveness of PEF measured by the game controller to bronchodilator. Future studies are needed to explore the characteristics of PEF measured by the game controller and whether it can help predict asthma exacerbations.

Conclusions

Our study evaluated the use of a novel airflow-based game controller coupled with a smart device serious game in children with asthma. Our game controller produced reproducible PEF measures that correlated well with several conventional spirometry measures and was highly appreciated by participants. Thus, our game controller, coupled with a serious game, may have the potential to increase adherence to PEF self-monitoring in children. Further studies are necessary to evaluate users' adherence over time, the validity of the game controller in different situations, and its impact on clinical outcomes, specifically its role in the prevention of asthma exacerbations.

Acknowledgments

We would like to thank Dr Alena Valderrama and Dr Valentin Gomez, who initiated the collaboration on games for asthma at Sainte-Justine hospital; Renaud Ory, Lucas Delvalle, Aminata Pierson, and Levan Jeanneret, who developed the initial version of *TikiFlow* in Switzerland; Collin Gallacher and Steve Ding, who developed the game controller building on the work of Tiberius Brastaviceanu and Jim Anastassiou in Canada; the teams and patients of Dr Isabelle Sermet-Gaudelus (Necker hospital), Dr Pierre-Régis Burgel (Cochin hospital), and Odile Flez (Fondation Arc-en-Ciel), who tested the game controller in France; all the families who participated in this study; the research support staff at each of two recruiting centers, specifically Mary-Ellen French, Louise Gosselin, Vincent Laguë, and Mylène Leblanc; and all other contributors to the initiative. This study was funded by a grant from the Canadian Institute of Health Research (CIHR), Strategy for Patient-Oriented Research program (#151755). Publication fees were paid by Dr. Sze Man Tse's research funds and the Breathing Games Association (Switzerland). The participatory design of the game and controller were funded by grants from CIHR (#151755), the French Hospitals Federation - Fonds FHF (#2017); Concordia University Council of Student Life (#63), Concordia University Sustainability Action Fund (#PYPF); Sainte-Justine health promotion and pulmonology services; Quebec university hospital; and Breathing Games Association. *TikiFlow* and the controller were initially developed at three cocreation events that were supported by Open Geneva, Swiss Game Center, Genevan Foundation against Cystic Fibrosis, Lift, University of Geneva, La Suite Necker, Hacking Health Besançon, Fablab Grand Besançon, and Maison des parents Besançon. The source code of *TikiFlow* [38] and the design of the controller [39] can be found online.

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Authors' Contributions

KC participated in the data collection, analyses and interpretation, and wrote the manuscript. FB participated in the design of the study and of *TikiFlow*. YG and CM participated in the design of *TikiFlow*. MB participated in the study design, data collection, and analyses. SMT participated in the design of the study, *TikiFlow*, data analyses and interpretation. FB and SMT secured funding for the study. All authors reviewed and approved the manuscript.

Conflicts of Interest

FB and YG cofounded the Breathing Games commons. The development of the game and game controller were led by Breathing Games. All other authors report no competing interests in this study.

Multimedia Appendix 1
Flowchart of patient enrolment in the study.
[PDF File (Adobe PDF File), 58 KB - games_v9i1e25052_app1.pdf]

Multimedia Appendix 2
Baseline characteristics of participants.
[PDF File (Adobe PDF File), 99 KB - games_v9i1e25052_app2.pdf]

Multimedia Appendix 3
Baseline lung function assessed by conventional spirometry.
[PDF File (Adobe PDF File), 15 KB - games_v9i1e25052_app3.pdf]

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Abbreviations

FEF_{25-75}: forced expiratory flow at 25%-75% of pulmonary volume
FEV_1: forced expiratory volume at 1 second
FVC: forced vital capacity
PEF: peak expiratory flow

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Original Paper

Physiological Responses and User Feedback on a Gameful Breathing Training App: Within-Subject Experiment

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Abstract

Background: Slow-paced breathing training (6 breaths per minute [BPM]) improves physiological and psychological well-being by inducing relaxation characterized by increased heart rate variability (HRV). However, classic breathing training has a limited target group, and retention rates are very low. Although a gameful approach may help overcome these challenges, it is crucial to enable breathing training in a scalable context (eg, smartphone only) and ensure that they remain effective. However, despite the health benefits, no validated mobile gameful breathing training featuring a biofeedback component based on breathing seems to exist.

Objective: This study aims to describe the design choices and their implementation in a concrete mobile gameful breathing training app. Furthermore, it aims to deliver an initial validation of the efficacy of the resulting app.

Methods: Previous work was used to derive informed design choices, which, in turn, were applied to build the gameful breathing training app Breeze. In a pretest (n=3), design weaknesses in Breeze were identified, and Breeze was adjusted accordingly. The app was then evaluated in a pilot study (n=16). To ascertain that the effectiveness was maintained, recordings of breathing rates and HRV-derived measures (eg, root mean square of the successive differences [RMSSDs]) were collected. We compared 3 stages: baseline, standard breathing training deployed on a smartphone, and Breeze.

Results: Overall, 5 design choices were made: use of cool colors, natural settings, tightly incorporated game elements, game mechanics reflecting physiological measures, and a light narrative and progression model. Breeze was effective, as it resulted in a slow-paced breathing rate of 6 BPM, which, in turn, resulted in significantly increased HRV measures compared with baseline (P<.001 for RMSSD). In general, the app was perceived positively by the participants. However, some criticized the somewhat weaker clarity of the breathing instructions when compared with a standard breathing training app.

Conclusions: The implemented breathing training app Breeze maintained its efficacy despite the use of game elements. Moreover, the app was positively perceived by participants although there was room for improvement.

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KEYWORDS

breathing training; serious game; biofeedback; mobile health; mHealth; mobile phone

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Introduction

Background

Slow-paced breathing has been shown to promote psychological well-being [1-3] and physiological outcomes [4-6]. It increases heart rate variability (HRV) [7], which is positively associated with levels of relaxation and cardiovascular health and can be beneficial for health outcomes such as stress [2,8], depression [3,9], anxiety disorders [10], hypertension [5,11], type 2 diabetes mellitus [12], and chronic pain [6]. Furthermore, slow-paced breathing training also shows promise for helping to control respiratory diseases such as chronic obstructive pulmonary disease [13]. As a result, the effectiveness of breathing training is often measured based on increases in HRV, which reflect activation of the parasympathetic nervous system and, thus, the level of relaxation [14].

These positive effects gave rise to many breathing training applications [15-18], digital experiences, and games that use breathing as a marker to help individuals reach a relaxed and mindful state [18,19] or manage specific health issues [20]. The core of these applications usually consists of animation providing periodic guidance based on an underlying breathing pattern that results in approximately 6 breaths per minute (BPM), for example, 4 seconds of inhalation, 2 seconds of exhalation, and 4 seconds of pause [4]. A small number of applications also use biofeedback, which promotes the effectiveness of breathing training [21,22]. Biofeedback is a technique in which individuals learn to adjust their behaviors by controlling certain physiological activities (eg, breathing rate). However, apps with biofeedback [16,20] often have limited scalability, as the acquisition of physiological data requires special hardware (eg, respiratory belt) to provide individuals with understandable real-time information to which they can respond. Moreover, the reach of many applications is even more limited, as their breathing training is branded as a meditative technique, which is rarely used by male and lower educated and physically inactive individuals [23]. Finally, it has been shown that although breathing training apps yield high numbers of installations, the retention rates and, thus, long-term adherence are very low [24].

To overcome the challenges of limited reach and long-term engagement, researchers and developers often draw knowledge from the game design literature to increase the experiential value in nongame domains, such as education [25], health [26], and information systems research [27,28]. Recently, researchers have started to develop design principles that rely on breathing information as sensory input for games [29]. Furthermore, applications have begun to provide interactive breathing training based on breathing information [16,20,30] or HRV measurements [18]. Although the latter provides information on the actual effect of the training, it is limited in providing responsive feedback. The reasons for this are that HRV is not a consciously controlled input, and because of its deferred nature, it cannot achieve a reaction in a fraction of a second. However, a real-time feedback loop in gameful breathing training requires such short reaction times. Although there are applications based on breathing-based biofeedback, they do not address the limitations on reach and scalability. The reason for this is that their designs focus on virtual reality [16] or desktop computer [20,30] setups that are not easily accessible to an individual.

Although the majority of the population owns a smartphone, the design of interactive mobile breathing training games remains sparsely explored. Furthermore, existing designs have their primary focus on stationary virtual scenes [16,20] instead of dynamic journeys that change with the training. Such constant visualization changes would be less repetitive when the breathing training lasts several minutes and when an individual performs it regularly.

There are 2 essential aspects to be considered when designing a biofeedback-based breathing training app: *biosignal* (ie, breathing patterns) detection and *biofeedback* visualization that is directly perceived by individuals. Designing such a visualization that incentivizes long-term adherence and is still effective is challenging. It is essential to ensure that the gameful design does not interfere with the actual objectives. Liu et al [28] used the term *meaningful engagement* to describe the relationship between the experiential and instrumental (nongame goal of the task) values of a gamified task, and they stated that both values should always increase together. This means that the gameful design should not introduce elements that may weaken the instrumental aspect of the task even if they increase the experiential value. Therefore, it is crucial to make task-specific design choices to increase the experiential value while maintaining or increasing the actual outcome of the underlying task. In the context of breathing training, gameful elements (experiential values) should not impair the effectiveness (instrumental value) of the training. Such impairments in the effectiveness could, for example, occur through overexcitation of the user.

Objectives

In a previous work, we introduced the gameful biofeedback breathing training *Breeze* [31] (Figure 1). In this study, we assessed the feasibility of detecting breathing patterns, that is, the *biosignal*, which is the first essential aspect of such breathing training. Although this study provided a high-level description of the mechanics of the visualizations and their acceptance in users, it did not provide detailed information about the design choices that guided the design of the second essential aspect of Breeze, namely, the *biofeedback* visualization. It also did not provide an in-depth analysis of its physiological efficacy. Consequently, this study aims to explain the design choices during the development process of Breeze and to provide a detailed analysis of physiological responses when compared with the standard breathing training. The long-term objective of such gameful breathing training is to foster long-term engagement. This study takes the first step by verifying that carefully designed gameful breathing training does not impair the physiological effects compared with the standard breathing training. It, therefore, asked the following research question: *Do gameful and nongameful breathing trainings trigger comparable physiological responses?* Given that gameful breathing training generated similar physiological responses, we asked the following research questions: *How are the different*

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components of the developed gameful breathing training perceived, and what are the implications for its future development?

Breathing training could be made gameful in various ways. We designed Breeze based on previous work on breathing training and biofeedback games and general design approaches used to induce relaxation. Physiological responses in participants of a pilot study were analyzed to answer the first research question. To answer the second set of research questions, we collected participant feedback regarding their perception of Breeze. The objectives of this study were as follows:

1. To present the development process of gameful and nongameful breathing trainings that share the same breathing pattern.
2. To assess the physiological responses to the gameful and nongameful breathing trainings.
3. To collect participant feedback on the gameful breathing training and to identify implications for future work.

Figure 1. Our developed mobile gameful biofeedback breathing training Breeze running on a smartphone.



Methods

Literature-Derived Design Choices

The main aim of the visual and interaction design is to foster relaxation and calmness in individuals while they remain motivated to continue. We, therefore, initially discussed fundamental building blocks for visual and interaction design (eg, colors, objects, game mechanics) and the psychological effects they trigger in individuals. These building blocks were then used together with existing design approaches for breathing training to produce a set of design choices for the development of our gameful breathing training.

Psychological Effects of Colors

Mehta and Zhu [32] found that blue colors triggered an approach and red colors triggered avoidance motivation. The use of blue colors, therefore, promotes more explorative and risky behavior, whereas the use of red colors results in a more vigilant and risk-averse state [33-35]. Whether this can be generalized to warm (eg, red, yellow) and cool (eg, blue, green) colors remains unclear. Nevertheless, additional research has indicated that cool colors have a calming and relaxing effect [36,37]. Thus, the use of cool colors, especially blue, was favored to induce more relaxation and calm in individuals. Furthermore, games that target the *explorer* player type [38] could potentially benefit from the enhanced explorative motivation of the individuals.

- Design choice 1. Use cool colors mainly to promote approach motivation and achieve a calming effect.

Environmental Influence on Well-Being

Research suggests that exposure to natural environments fosters relaxation and mental well-being [39,40]. Multiple projects have leveraged these findings [19,41]. Patibanda et al [16] confirmed this in the context of breathing training. They found

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that simple visuals of natural objects, such as trees, leaves, and water, helped participants relax and remain calm while playing a virtual reality game.

Nevertheless, the underlying mechanisms that induce relaxation in individuals when experiencing nature are still unclear. One influencing factor appears to be noise exposure in natural environments when compared with urban environments [42]. For example, a study showed that exposing stressed individuals to natural sounds improved their ability to recover from a stressful situation [43]. However, because we rely on the microphone of the mobile device for breathing detection, we may not be able to play sounds. Moreover, other theories provide suggestions that do not rely on sound. One states that exposure to nature activates the parasympathetic nervous system and thus reduces stress [39]. According to this theory, this activation could originate in the evolution of humankind because grassy environments with trees are usually a better source of food and shelter. On the basis of this line of argument, research has also suggested that people have an intrinsic preference for natural landscapes, in particular natural greenspaces, compared with urban landscapes [40,44].

However, research has shown that actual natural environments are not required to cause these effects. Researchers have found that simply showing images and videos of natural scenes was sufficient to reduce stress in participants [45].

To conclude, researchers are still investigating the underlying mechanisms of action. Nevertheless, studies have shown promising effects on stress, relaxation, and calmness levels of individuals when exposed to nature. From this, we derived that using a peaceful natural environment is beneficial by inducing a calming effect in individuals.

- Design choice 2. Use a natural and peaceful environment to induce a calming effect and a sense of well-being.

Increased Experiential Value Through Game Elements

The main purpose of increasing experiential value is to broaden the target audience for breathing training and to improve long-term adherence by engaging and motivating individuals. Classic approaches include adding game elements such as leader boards, achievements, and point gathering to otherwise monotonous tasks [28,46]. However, it is crucial to ensure that the employed game elements do not interfere with the underlying task and, for example, decrease its instrumental value [28], be it the amount of text produced by a writer or the health benefits for a patient. However, experiential value is affected by not only the employed game elements themselves but also the feel of the game dynamics. When physiological sensors influence the game state, this is especially important. Nacke et al [47] recommend mapping physiological sensors that have a direct impact on a game to actions in the virtual world. Sicart [48] defines actions (methods invoked by agents that interact with the game state) to be game mechanics. On the basis of these 2 references, we concluded that mapping direct physiological inputs to game mechanics can help improve the feel of game dynamics.

- Design choice 3. Integrate breathing guidance and biofeedback into the context as much as possible but never at the cost of comprehensibility.
- Design choice 4. Have the input from physiological measures reflected as game mechanics.

An essential part of increasing an individual's enjoyment and thereby the experiential value is to add a kind of progression model toward a goal to help keep the individual motivated to carry on. For a task such as breathing training, a progression model is especially relevant as the individual is required to stay focused for a specified period. Many gamification approaches provide such a mechanism. A simple example would be to show a score at the end of a session. Although this can increase the willingness of an individual to return and try to reach a higher score [49], it does not necessarily motivate individuals during a session. It is, therefore, essential to give individuals a continuous feeling of progress throughout a session. One possibility would be to continuously change the appearance of an object or shift the viewport into new environments. In *Life Tree*, the saturation level of a tree provides a sense of progress [16]. However, one game session lasts approximately 2.5 min. It is questionable whether this progression model yields sufficient diversity with a longer playing time.

Games often achieve this by applying flow theory [50]. With regard to gameplay, the theory states that a game's difficulty should gradually scale with the abilities of the individual playing it. This way, the individual is still challenged but not overwhelmed and thus attains flow in the activity. Although most research has focused on gameplay to drive flow, narrative engagement can achieve the same result. As previous research has shown, the concepts of flow, narrative engagement, and enjoyment are highly correlated and often inseparable [51]. The challenge in the context of gameful breathing training is to not overexcite the individual. As a result, changing difficulty levels and challenges can be difficult. Another solution could be to use embedded narratives to give the virtual world some more variety [52] and keep the individual engaged. These narratives do not have to be explicitly told (eg, through dialogues between characters); however, they can be hinted at and then left entirely to the imagination of the individual. A way of achieving this can be to design the virtual world in a way that it tells its story by itself, for example, by adding specific objects to it. We concluded that a continuous progression model is required that motivates individuals while not overexciting them. A possible solution could be to employ light forms of embedded narratives.

- Design choice 5. Provide a continuous feeling of progress toward a goal without overexciting the individual.

System Design and Development

Our gameful breathing training Breeze uses a breathing training duration of 6 min and a 4-2-4-second inhale-exhale-pause breathing pattern, as in Russell et al [4]. The virtual world is set in a natural environment, where the individual helps a boat travel downriver by controlling the wind's strength through breathing.

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Implementation of the Design Choices

In the following paragraphs, we discuss how the design choices have been implemented in Breeze.

Design Choice 1 and Design Choice 2: Peaceful Natural Environment

The first 2 design choices, using natural environments and cool colors, are best addressed together. We made use of many natural objects (eg, trees, bushes, mountains) with mostly cool colors. For a simplistic look and to ensure that the app ran smoothly on mobile phones, we used meshes with a low polygon count and mostly flat shading.

Design Choice 3 and Design Choice 4: Integration of Guidance and Biofeedback

Wind is the main component that indicates the breathing pattern. We used tailed particles to visualize the wind. When the wind particles move in the opposite direction to the boat's movement and toward the viewport, they indicate the inhalation phase. The exhalation phase is indicated when the wind particles move in the same direction as the boat and away from the viewport. During the pause phase, the wind has no particular direction and the number of particles is drastically reduced. To further help individuals stick to the breathing pattern, we added a semitransparent user interface (UI) element to the game, which also shows the current breathing phase (*arrow down=inhalation*; *arrow up=exhalation*; *horizontal line=pause*).

The wind's strength reflects the breathing input. There is a set of mechanisms that determine how the breathing input affects the wind's strength and, consequently, the biofeedback. The reaction of the game state is mainly dependent on the current breathing phase based on the periodic breathing pattern. If the system detects an inhalation or exhalation during the same breathing phase indicated by the breathing pattern, the game state is affected. In the following paragraph, we call these 2 cases *correct inhalation* and *correct exhalation*. It is important to note that we differentiate between whether a correct inhalation or exhalation occurs for the entire period of the corresponding phase indicated by the breathing pattern or just for a fraction of it.

Correct inhalation has 2 consequences. First, the wind's strength increases. Second, the possible maximum acceleration for the next exhalation phase continuously increases until it reaches a predefined maximum value or the correct inhalation ends. During a correct exhalation, the wind's strength also increases, and thus, the boat accelerates. The preceding inhalation phase thereby determines the acceleration strength. If correct exhalation does not follow correct inhalation, the boat still has additional acceleration by some small but perceivable amount.

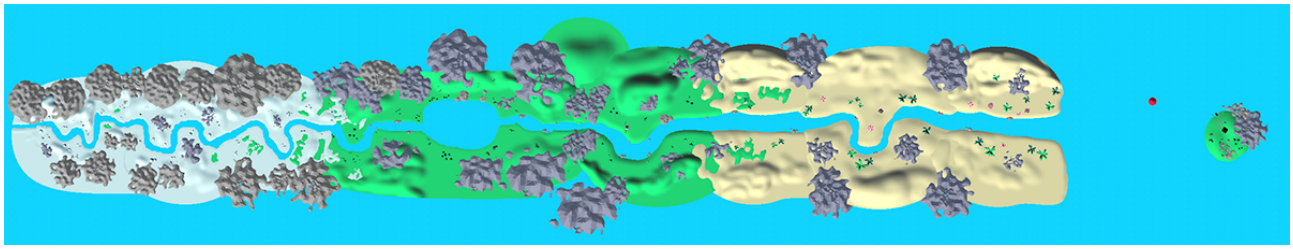
To provide comprehensive visual feedback that is well incorporated into the virtual world, the wind's strength influences a variety of other elements. The wind inflates and deflates the sail more or less depending on the wind's strength. The amount of inflation then influences the boat's speed, which is additionally accentuated by the size of the waves behind the boat.

The wind's strength is portrayed by increasing the number of particles and increasing their speed.

Design Choice 5: Movement and Environment Design

The boat continuously travels through a changing environment to convey a feeling of progress. To prevent overexcitement that could impair the individual's relaxation, we used a mostly static environment. However, the environment changes several times throughout 1 training session, thereby introducing some sense of narrative. The complete environmental design is depicted in Figure 2. The boat starts in a snowy landscape and advances into a grass-overgrown environment where the river merges into a small lake. Later, the boat passes the sandy beaches before sailing into the open sea. The boat may not reach the beaches or the open sea because the distance covered depends on the individual's breathing performance. In the end, Breeze shows the distance achieved to give a sense of achievement. In the future, this score could also be used to motivate individuals to make improvements or could be compared with other people's scores.

Figure 2. The environment design of Breeze is depicted. It starts in a snowy environment, passes into a grass-overgrown environment, and passes the sandy beaches before leading into the open sea.



Pretest and Consequent Design Changes

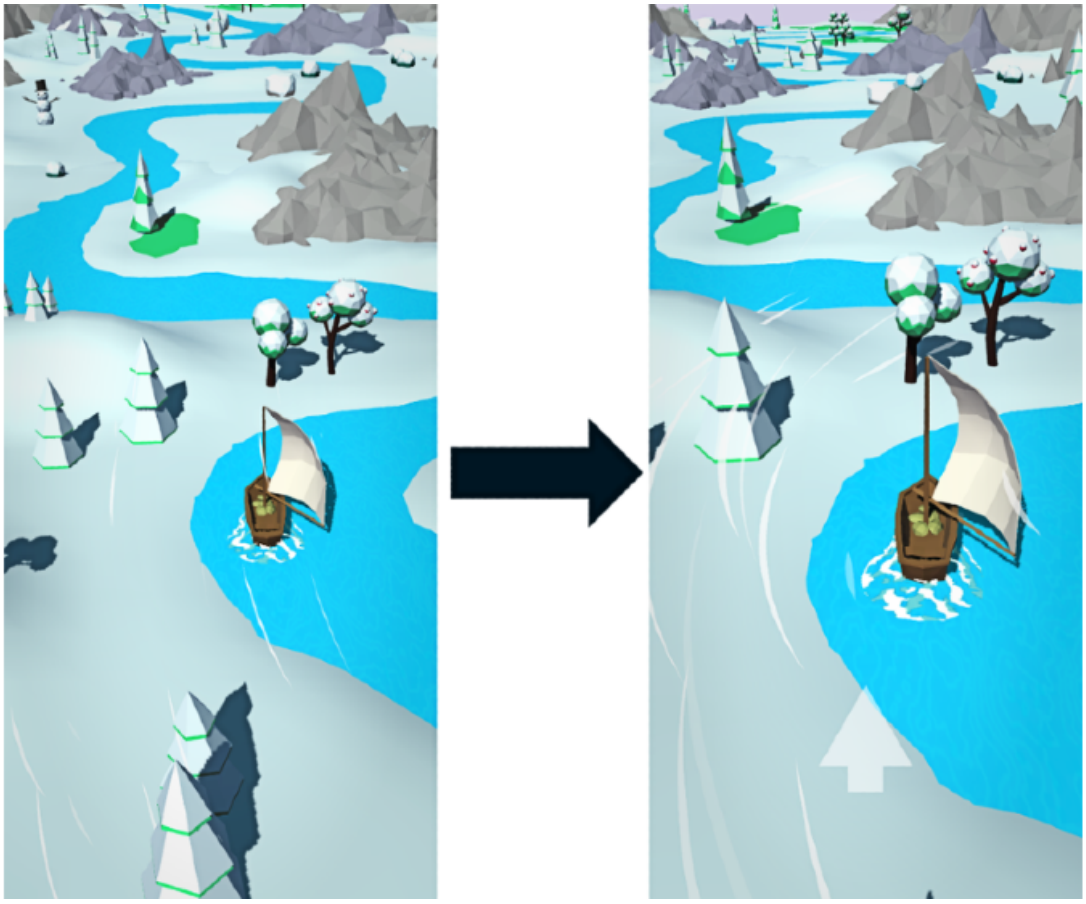
The first version of Breeze was evaluated in a pretest. The findings led to 2 additional design choices and consequent adaptations to Breeze. The versions of Breeze before and after the pretest are depicted in Figure 3. In the pretest, 3 male participants, with an average age of 31 years (SD 2.45) and no previous knowledge about the app, were asked to conduct a breathing training session using Breeze and provide feedback. Even though they liked the overall setting and design of the experience (eg, 1 participant stated, "Nice graphics and landscape, the wind animation is good."), they pointed out that it was not always easy to follow the breathing pattern. A participant stated that it needs "clearer guidance of breath in and out," and another participant mentioned that the "animations are too small - difficult to follow." Thus, the feedback mostly regarded the guidance component of Breeze. We attribute this to the fact that the guidance in this complex scene was not as

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pronounced compared with classic breathing training visualizations. Therefore, it was crucial to have guidance elements that were well separated from the background and in a concentrated area on the screen to form a clear focal point. Elements that cover a large surface are possible; however, they need to overlap this focal point. As a result, we made several adaptations to the visualization of the guidance system in Breeze:

1. The in-game camera was moved closer to the boat, which made the effects on the sail and the waves easier to identify.
2. The number of wind particles and the thickness of their trajectories were increased for clearer visuals.
3. A basic acceleration was introduced when the wind moved with the boat (exhalation) for better incorporation into the world's context (following design choice 3).
4. An additional semitransparent UI element was added to indicate the current breathing phase (following design choice 3).

Figure 3. Breeze before (left) and after (right) applying design changes to address problems identified in the pretest. Specifically, the camera was moved closer to the boat, the wind particles were made more pronounced, and an additional user interface element was introduced to indicate the current breathing phase. There were also changes made to the boat's acceleration behavior that are not specifically visualized.



Because biofeedback and guidance are closely coupled, changes to the guidance system also require changes to the biofeedback mechanisms:

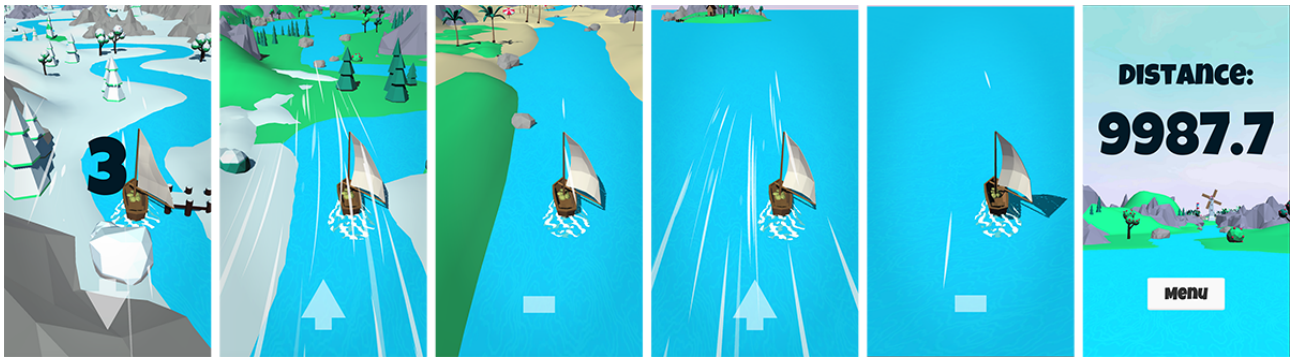
1. Because there is a basic acceleration of exhalation, the acceleration triggered by a correct exhalation was increased, so it remained noticeable (following design choice 3).
2. To fine-tune the feedback with regard to the basic acceleration, the maximum reachable acceleration was increased (following design choice 3).

Gameplay Overview

The game starts on a menu screen, where a breathing training session can be started. After clicking *start*, the view changes into game mode. The different stages of gameplay and the boat's journey are depicted in Figure 4. In the beginning, the boat is standing still at a pier. At the end of a countdown, the 4-2-4 breathing pattern starts with an inhalation phase, and the boat starts moving at a constant pace. The individuals then have to adjust their breathing to the breathing pattern by following the guidance system. Depending on the ability of the individual to do so, the boat accelerates during exhalation. During the inhalation and pause phases, the boat's speed always slowly decreases. The boat travels through the changing environment until 6 min have elapsed. When finished, the distance traveled is shown. A video of Breeze is provided in Multimedia Appendix 1.

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Figure 4. All phases of a breathing training session from Breeze are depicted from left to right: countdown, traveling from a snowy to grassy landscape, traveling from a grassy landscape to sandy beaches, reaching the open sea by passing a small island, traveling further into the sea, and finally, the score screen showing the distance traveled.



Detection

The app uses a microphone to detect the different breathing phases (inhalation, exhalation, and pause). The algorithm is described in Shih et al [31].

Implementation

The gameful UI with biofeedback was created using the Unity game engine (version 2019.1.8). All models were designed and animated using 3D modeling software Blender.

Pilot Study Design

A pilot study was conducted to assess how Breeze was perceived (qualitative questions) and whether it reached a physiological response comparable with that of the standard breathing training (physiological measurements). The study was reviewed and approved by the ethics committee of ETH Zürich (ID: 2019-N-91). To this end, we compared Breeze with the standard slow-paced breathing training [4], which we refer to as *Circle* in this paper (Figure 5).

Figure 5. Visualization of the standard breathing training Circle. It served as a comparison for the impact of Breeze on participants' HRV measures. This way, the authors were able to ensure that Breeze yields similar physiological results although it employs game elements.



Physiological Measurements

The instrumental value of breathing training can be characterized as an increase in certain HRV measures. Our aim is to verify that Breeze has a comparable impact on HRV as that of Circle. We used *BioPac's Smart Center Stand-alone BioNomadix Wireless System* to record heartbeat and derived several HRV measures from it. Furthermore, the breathing rate (BPM) and the abdominal respiration amplitude (ARA) were monitored through a respiratory belt. We used a sampling rate of 2000 samples per second for all measures. The different physiological measures that were studied in this study included the following [4,14,53]:

- Heart rate (HR): It is the number of heart beats per minute.
- High-frequency HRV (HF-HRV): It is the portion of the beat-to-beat intervals from 0.15 to 0.4 Hz. It is an indicator of the parasympathetic tone for breathing rates between 9 and 24 BPM [4].

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- Low-frequency HRV (LF-HRV): It is the portion of the beat-to-beat intervals from 0.04 to 0.15 Hz. It is an indicator of oscillations in the baroreflex.
- Very-low-frequency HRV (VLF-HRV): the portion of the beat-to-beat intervals from 0.0033 to 0.04 Hz. This measure normally yields only small variations that are induced by breathing.
- Low- to high-frequency ratio (LF/HF ratio): It is the ratio between the low- and high-frequency portions of the beat-to-beat interval. This measure is thought to represent the sympathetic-vagal balance. However, this interpretation has been highly disputed [53]. Nevertheless, we include the measure in the analysis for completeness.
- Interbeat interval (IBI): It is the mean of the distances between different beats.
- Standard deviation of normal R-R intervals (SDNN): It is a representative measure of variability and is thus linked to the overall HRV.
- Root mean square of the successive differences (RMSSDs) between adjacent heartbeats: It is an appropriate indicator of parasympathetic tone when the breathing rate differs from 9 to 24 BPM. Therefore, RMSSD is an ideal measure for parasympathetic tone when at least 5 min of HR data are available.
- pNN50: It is the percentage of R-R intervals that are greater than 50 milliseconds away from adjacent intervals.
- Breathing rate (in BPM): It is the number of full respiration cycles per minute (inhalation, exhalation, and pause).
- ARA: It is the abdominal movement measured in volts.

Due to concerns regarding sphericity and the non-normal distribution of the baseline measurements as a result of the sample size, we used the nonparametric Friedman test as the omnibus test. Measures that yielded significant differences were then analyzed using the pairwise Wilcoxon signed-rank test. Compared with a previous work [31], we provide detailed physiological analyses in this study using all collected measures, consistent with established approaches [4].

We treated RMSSD as the main outcome for efficacy in this study. The reason for using RMSSD is its high correlation with other important measures, such as HF-HRV. Furthermore, in contrast to HF-HRV, RMSSD has the characteristic that it remains an appropriate indicator of parasympathetic tone when the breathing rate is lower than 9 BPM [4]. Nevertheless, as all the measures offer different perspectives on the outcomes, we provide a complete analysis for all of them. This allows us to discuss Breeze's potential strengths and weaknesses in more detail. Consequently, the following hypotheses were tested:

1. There will be a difference in physiological response between Circle and the baseline assessment.
2. There will be a difference in physiological response between Breeze and the baseline assessment.
3. There will be no difference in physiological response between Circle and Breeze.

Self-Report Instrument

To gather feedback on Breeze, we asked participants 2 open questions at the end of the study:

1. What are positive aspects about using the sailboat breathing training?
2. What suggestions do you have for the sailboat breathing training?

The responses were then systematically coded by employing deductive coding by 2 of the authors [54]. All the code used and their descriptions can be found in Multimedia Appendix 2. After this initial coding round, we computed the raw agreement and Cohen kappa. Both coders then discussed their mismatches and were given 1 of the following 3 actions for each mismatch: favoring one coding over the other, merging the 2 codes, or finding a new coding.

Recruitment

A total of 16 participants (7 females) between 21 and 32 years old (mean 24.6, SD 3.44) were recruited at the first and last authors' institutions. Participation was voluntary and compensated in local currency worth US $20.

Procedure

First, participants were welcomed in a quiet environment and asked to sit quietly for 6 min to collect data on their physiological baseline. Next, we sequentially presented Breeze and Circle to the participants. The participants used the 2 training sessions in random order. There was a washout period of 5 min between the training sessions to avoid carryover effects. For each training, the participants first familiarized themselves with the breathing training and then performed it for 6 min. After completing both trainings, participants filled in a qualitative questionnaire regarding their experience with Breeze. The study lasted approximately 50 min per participant. The study setup is shown in Figure 6.

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Figure 6. Experimental setup.



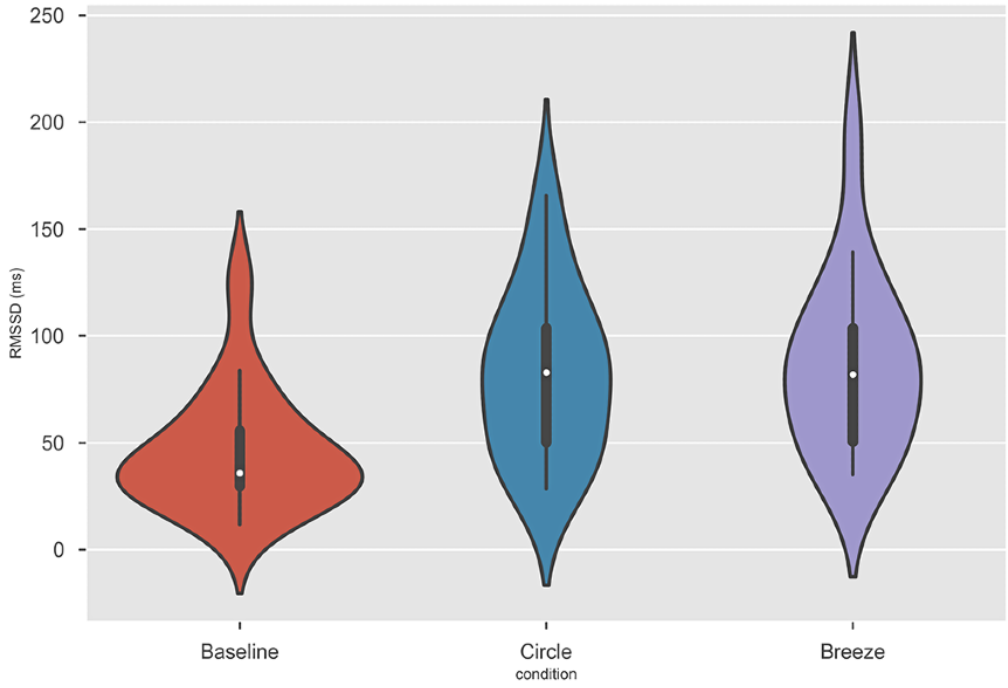
Results

Physiological Responses to Breathing Trainings

Because the distributions of some measurements did not pass checks for normality, nonparametric methods were used to analyze data. For the main outcome RMSSD, the measurement distributions in all conditions are shown in Figure 7. The mean, SD, median, and interquartile ranges for all measures in each condition (the baseline, Circle, and Breeze) are provided in Table 1.

Friedman tests were applied as omnibus tests to all measures across the 3 conditions. The results of the omnibus tests are shown in Table 2. At a significance level of α=.05, there were significant differences for all measures except VLF-HRV and ARA. All other measures were further analyzed using pairwise Wilcoxon signed-rank tests. The results are shown in Table 3.

Figure 7. Violin plots depicting the distribution of the root mean square of the successive differences (RMSSD) measurements in all the 3 conditions. Each violin plot's outer shape represents the complete distribution of the sample. In addition, standard boxplots with the medians represented by white points are included.



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Table 1. Assessment of physiological measures.

Variable	Baseline		Circle		Breeze	
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
IBI[a]	837.25 (127.14)	836.00 (739.00-953.75)	857.00 (121.32)	842.50 (772.00-950.75)	843.75 (117.23)	835.50 (769.25-929.00)
HR[b]	73.31 (11.77)	72.00 (62.75-81.25)	71.50 (10.53)	71.50 (63.25-77.75)	72.31 (10.42)	71.50 (64.25-77.75)
SDNN[c]	53.65 (30.00)	45.30 (39.32-62.83)	102.52 (36.16)	106.60 (74.47-118.68)	111.81 (35.71)	104.65 (81.48-127.15)
RMSSD[d]	45.97 (28.05)	35.75 (29.65-55.62)	81.86 (39.20)	82.85 (50.17-103.55)	86.42 (41.56)	82.00 (50.53-103.50)
pNN50[e]	24.17 (20.86)	15.22 (8.56-37.66)	33.17 (15.42)	31.30 (27.41-39.15)	38.17 (16.16)	34.94 (27.84-53.48)
HF-HRV[f]	1073.00 (999.32)	812.00 (435.25-1269.50)	2067.06 (1826.66)	1762.50 (480.50-2861.75)	2696.62 (2830.56)	2186.00 (720.00-2795.75)
LF-HRV[g]	2530.00 (5189.85)	977.50 (563.75-1825.00)	8406.44 (5593.35)	7500.50 (4359.00-10,320.25)	10346.31 (6103.83)	7804.00 (6272.50-13,844.00)
VLF-HRV[h]	82.81 (140.09)	43.50 (18.25-72.50)	84.00 (127.36)	49.00 (20.00-70.75)	120.94 (119.60)	64.50 (37.75-182.50)
LF/HF ratio[i]	2.76 (4.83)	1.35 (0.82-1.64)	6.49 (4.65)	4.29 (3.11-8.36)	6.33 (3.99)	5.72 (2.91-9.09)
BPM[j]	12.23 (4.10)	11.83 (10.29-13.38)	5.99 (0.04)	6.00 (6.00-6.00)	5.96 (0.10)	6.00 (5.83-6.00)
ARA[k]	5.34 (2.40)	5.78 (3.33-6.58)	4.44 (3.09)	6.09 (1.34-6.44)	4.32 (2.84)	4.75 (2.08-6.62)

[a]IBI: interbeat interval.

[b]HR: heart rate.

[c]SDNN: SD of normal R-R intervals.

[d]RMSSD: root mean square of the successive differences.

[e]pNN50: percentage of normal R-R intervals greater than 50 milliseconds than their adjacent one.

[f]HF-HRV: high-frequency HR variability.

[g]LF-HRV: low-frequency HRV.

[h]VLF-HRV: very-low-frequency HRV.

[i]LF/HF ratio: low- to high-frequency ratio of heart rate variability.

[j]BPM: breaths per minute.

[k]ARA: abdominal respiration amplitude.

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Table 2. Omnibus tests (Friedman) of within-subject effects.

Variable	Q (*df*)	*P* value
IBI[a]	7.625 (2)	.02
HR[b]	7.429 (2)	.02
SDNN[c]	25.125 (2)	<.001
RMSSD[d]	24.0 (2)	<.001
pNN50[e]	10.889 (2)	.004
HF-HRV[f]	15.5 (2)	<.001
LF-HRV[g]	19.5 (2)	<.001
VLF-HRV[h]	2.0 (2)	.37
LF/HF ratio[i]	14.0 (2)	<.001
BPM[j]	21.709 (2)	<.001
ARA[k]	1.175 (2)	.56

[a]IBI: interbeat interval (milliseconds).

[b]HR: heart rate (beats per minute).

[c]SDNN: standard deviation of normal R-R intervals (milliseconds).

[d]RMSSD: root mean square of successive differences between adjacent heartbeats.

[e]pNN50: percentage of normal R-R intervals that are greater than 50 milliseconds away from their adjacent intervals.

[f]HF-HRV: high-frequency heart rate variability (0.15-0.4 Hz).

[g]LF-HRV: low-frequency heart rate variability (0.04-0.15 Hz).

[h]VLF-HRV: very-low-frequency heart rate variability (0.0033-0.04 Hz).

[i]LF/HF ratio: low- to high-frequency ratio of heart rate variability.

[j]BPM: respiration cycles per minute.

[k]ARA: abdominal respiration amplitude (volts).

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Table 3. Pairwise comparisons between baseline, Circle, and Breeze using the Wilcoxon signed-rank test.

Variable and condition	Comparison condition	Median of differences	Difference IQR	W statistic	*P* value[a]	RBC[b]
IBI[c]						
Circle	Baseline	22.00	6.75 to 39.50	19	.01[d]	0.721
Breeze	Baseline	5.50	–8.25 to 23.25	52	.42[d]	0.235
Breeze	Circle	–18.00	–25.00 to –3.00	28	.04[d]	–0.588
HR[e]						
Circle	Baseline	–2.00	–4.00 to 0.00	15	.02[d]	–0.714
Breeze	Baseline	–0.50	–1.25 to 0.25	27	.36[d]	–0.308
Breeze	Circle	1.00	0.00 to 1.50	28	.12[d]	0.467
SDNN[f]						
Circle	Baseline	42.55	28.77 to 72.62	0	<.001	1.0
Breeze	Baseline	57.10	37.83 to 72.62	0	<.001	1.0
Breeze	Circle	9.45	–2.37 to 21.72	27	.03	0.603
RMSSD[g]						
Circle	Baseline	26.40	15.98 to 58.38	0	<.001	1.0
Breeze	Baseline	38.95	15.65 to 64.40	0	<.001	1.0
Breeze	Circle	1.15	–2.07 to 11.60	44	.23	0.353
pNN50[h]						
Circle	Baseline	13.28	2.55 to 16.45	24	.02	0.647
Breeze	Baseline	16.59	4.62 to 25.76	14	.003	0.794
Breeze	Circle	2.29	0.48 to 11.51	16	.01[b]	0.733
HF-HRV[i]						
Circle	Baseline	496.00	142.75 to 1758.25	12	.002	0.824
Breeze	Baseline	1095.50	403.75 to 2038.75	14	.003	0.794
Breeze	Circle	361.50	93.00 to 855.00	25	.02	0.632
LF-HRV[j]						
Circle	Baseline	5132.50	2173.25 to 8368.75	1	<.001	0.985
Breeze	Baseline	7027.50	4975.25 to 9084.75	1	<.001	0.985
Breeze	Circle	1665.00	–1134.75 to 3819.50	30	.05	0.559
LF/HF ratio[k]						
Circle	Baseline	2.76	1.65 to 6.67	16	.005	0.765
Breeze	Baseline	3.39	1.57 to 6.37	16	.005	0.765
Breeze	Circle	–0.31	–1.30 to 0.62	59	.670	–0.132
BPM[l]						
Circle	Baseline	–5.92	–7.38 to –4.29	1	<.001[d]	–0.985
Breeze	Baseline	–5.83	–7.38 to –4.29	1	<.001[d]	–0.985
Breeze	Circle	0.00	–0.17 to 0.00	8	.30[d]	–0.429

[a]Reported *P* values are exact wherever possible.

[b]Effect size is reported through the rank biserial correlation.

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[c]IBI: interbeat interval measured in milliseconds.

[d]*P* value was calculated through normal approximation because of ties.

[e]HR: heart rate measured in beats per minute.

[f]SDNN: standard deviation of normal R-R intervals measured in milliseconds.

[g]RMSSD: root mean square of successive differences between adjacent heartbeats.

[h]pNN50: percentage of normal R-R intervals that were greater than 50 milliseconds away from their adjacent intervals.

[i]HF-HRV: high-frequency heart rate variability (0.15-0.4 Hz).

[j]LF-HRV: low-frequency heart rate variability (0.04-0.15 Hz).

[k]LF/HF ratio: low- to high-frequency ratio of heart rate variability.

[l]BPM: respiration cycles per minute.

Coded User Feedback

This section summarizes the information gathered through the coding of participant feedback. The codes used are *Gamification*, *Visualization*, *Guidance*, *Biofeedback*, *Circle versus Breeze*, *RelaxationEffect*, and *To add*.

The initial coding round, performed by 2 of the authors as independent coders, yielded a raw agreement p_o of 0.843 and Cohen κ of 0.812, indicating almost perfect agreement [55]. The main difference came from an inherent overlap of the code To add and the other codes. For example, coder 1 often only assigned the code Gamification when a participant criticized a game element and proposed changing it, whereas coder 2 favored the code To add in such circumstances. The coders came to a consensus by merging all but one mismatch, thus assigning both codes. In one case, they decided to use the coding provided by coder 1.

Because the narrative game element is mainly implemented through visualization, we combined the codes *Gamification* and *Visualization* in one section in the subsequent sections. The information yielded by the code *Circle versus Breeze* is incorporated into specific topics. Any quantitative numbers were calculated by counting the number of participants who made a statement that was assigned a specific code.

Gamification and Visualization

Thirteen participants wrote in their feedback that they enjoyed specific game elements or gamification overall. They mainly highlighted the score at the end and liked the playfulness compared with Circle. Two participants suggested increasing the gamification level by, for example, providing the score during breathing training. Another 4 expressed interest in receiving more breathing statistics at the end. Two participants explicitly mentioned that Breeze is more exciting than Circle: for example, “The feeling of accomplishment after doing the exercise in comparison with the feeling of nothing after the circle version.” Fourteen participants made supporting statements about the visualization and the narrative of the breathing training. These statements ranged from specifically visual standpoints, “The sailboat looks great,” to the appreciation of the narrative context, “The sailing boat topic for relaxation is awesome!” The natural setting of the virtual world was appreciated as calming and relaxing. Despite overall positive feedback regarding the visualization and narrative, 11 participants suggested improvements. One participant felt that the app was more appropriate for children than for adults, even though they liked the graphics overall. However, many improvement suggestions were given regarding the UI guidance symbols, such as “cooler symbols” or “It made the visuals redundantly cluttered.” Only one participant perceived that the gameful elements would corrupt their breathing, as they gave them the urge to test the limits of the app rather than follow the training correctly.

Guidance

Five participants positively emphasized the guidance in Breeze. One even felt that it was easier to follow than the standard breathing training: “easy to follow, easier than the circle.” Six participants had some ideas for improvement. One participant pointed out that the exhalation phase of the 4-2-4 breathing pattern is too short according to their personal preference. Three of them had difficulties following the guidance itself. The main issue was to anticipate the change between 2 breathing phases. One of them stated regarding the guidance elements: “they can’t be easily anticipated like the circle version.” Another participant who experienced similar issues suggested combining the circle animation with the sailboat to arrive at clearer guidance. Nevertheless, the majority of the participants were able to follow the training, even though it was surprising for some of them: “I thought it would be little distracting at first, but it was not. I was able to follow the exercise properly.”

Biofeedback

Because the biofeedback was triggered by the individuals’ input to the app, it was closely linked to feedback regarding overall gamification. Nevertheless, 5 participants explicitly pointed out that they liked receiving biofeedback. One participant even stated, “I feel the feedback system helps you be more relaxed.” This was in contrast to 2 other participants who felt that their breathing was not accurately detected.

Nevertheless, 3 participants suggested some improvements. One participant would have liked to have received statistics about their breathing performance during and after the breathing training. The other 2 suggested that the influence of the breathing input was more pronounced in the visualizations. One stated, “Improve the effects when the user is breathing, so they can better feel they are moving the boat.”

To Add

Five participants stated that they would have liked to have some background music and sound effects. One suggested using music as an additional measure to promote relaxation. Another participant thought that adding specific sound effects to the biofeedback could be beneficial: “Sound feedback to further motivate and reassuring the user that he's breathing correctly.”

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Another aspect mentioned by the participants was to add an element that lets the user know the remaining time for the current session. Furthermore, one participant suggested not only showing the score at the end but also setting a leaderboard to set a relative benchmark for their performance.

Discussion

Physiological Responses

The breathing rates of participants for the standard breathing training and Breeze clearly showed that both were effective in guiding slow-paced breathing with 6 BPM. The HRV measurements also showed an effect in both conditions. The differences between the conditions for these measurements were also consistent with previous work [4]. The only exception was that we found a significant difference in p50NN. Analysis of RMSSD showed that both conditions had a significant effect when compared with the baseline measurements. Comparing Breeze with the standard breathing training showed no significant difference. This conclusively confirmed the hypotheses for RMSSD. Furthermore, the comparison with the baseline yielded a perfect rank biserial correlation, supporting the claim of the presence of a large effect for both the standard breathing training and Breeze when compared with the baseline. The nonsignificant difference between Breeze and the standard breathing training with a very small median of differences was in line with the objective of reaching a comparable relaxation effect with Breeze.

The standard breathing training was able to slightly but significantly increase IBI and reduce HR, whereas Breeze did not yield a significant difference from the baseline for either measure. Although these measures were not the main outcome, they could have positively influenced HRV measures. However, important HRV measures (eg, HF-HRV, SDNN, or p50NN) yielded results comparable with those of RMSSD. Comparisons of the 2 conditions sometimes favored Breeze. Most notably, the HF-HRV measures were significantly higher for Breeze. Although the limited sample size does not allow for any conclusive reasoning, this should be further investigated with a larger sample.

Although VLF-HRV measures were elevated with both breathing trainings, they did not significantly differ from the baseline, consistent with previous work [4]. In addition, for ARA, no significant differences were found, which was also in line with previous work [4]. In our case, Breeze yielded slightly lower values than the baseline and the standard breathing training. This indicates that the participants did not breathe as much into the abdomen when using Breeze. Because this was driven by a small number of participants, we attribute this to the finding that Breeze's breathing guidance requires further improvements. In addition, as stated by one participant, another factor could be that the game elements may have caused some participants to feel the urge to experiment with their way of breathing. Nevertheless, the overall findings support the claim that Breeze had comparable effects on HRV as those of the standard breathing training. From this, we conclude that Breeze achieved the main objectives of slow-paced breathing training despite the use of richer graphics and game elements.

User Feedback

In this section, we discuss participants' feedback regarding Breeze. This is discussed in relation to the design choices that guided the implementation of Breeze.

Cool Colors and Natural Setting

The qualitative feedback shows that participants valued the environment and sometimes even explicitly pointed out the relaxing factor of nature. Thus, design choice 1 and design choice 2 appeared to be effective strategies to foster relaxation in individuals and were potentially beneficial for the instrumental value. They also contributed to an increase in the experiential value for several participants. These results support existing studies regarding color [36,37] and nature [39,40,44] perception and apps [16,19,41] already relying on the calming effect of nature.

Guidance and Biofeedback

The guidance and biofeedback that we implemented in Breeze were mainly driven by design choice 3. If not done well, it could have led to unclear guidance and biofeedback, thereby impairing the instrumental value or resulting in clear but incongruous guidance and biofeedback that breaks the immersion. Poor implementation could have even decreased the experiential value.

In Breeze, the increase in the wind's strength and acceleration of the boat appeared to be adequate biofeedback for correct breathing. However, periodic guidance through the wind and UI symbols seemed to be the weakest component. Although they provided sufficient guidance to correctly follow the breathing training, several participants did not like the UI symbols, even though some others valued them as additional help. Nevertheless, the UI symbols violated design choice 3, as they were not neatly incorporated into the virtual world. The use of these UI symbols was, therefore, a design flaw within Breeze that triggered some participants' responses. However, the participants who stated that they mostly relied on the UI symbols for guidance also often provided positive remarks about the movement and acceleration of the boat based on their breathing. Thus, they were still able to correctly follow breathing training through the symbols and consider biofeedback. Nonetheless, we plan to remove the UI symbols in favor of an additional guidance system that is well incorporated into the app's world and, thus, improve compliance with design choice 3 (eg, more pronounced guiding animation by the sail).

User interactions with the experience were heavily influenced by design choice 4. As a result, this design choice is strongly linked to biofeedback and the gamification of breathing training. Being able to influence the experience through breathing at the right moment and consequently receiving biofeedback was valued by many participants. This supports the underlying findings of previous work that sensor inputs should be reflected as actions in the game [47]. The participants who expressed problems with biofeedback mostly stated that they did not feel that they had an impact on the app through their breathing. We do not attribute this to bad biofeedback design but to imperfect breathing detection for these individuals, which is possible based on some people's breathing (eg, exceptionally silent inhalation

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or exhalation). However, this is not the focus of this paper and is discussed in detail in Shih et al [31], and it remains a major priority for our future work.

Progression Model

The implementation of design choice 5 was generally well received. Many participants explicitly mentioned that they liked the continuous progression through the virtual world. Several participants also had a sense of achievement when the distance traveled was presented, which supports the existing gamification literature regarding the motivational effect of extrinsic rewards [56]. Participants' statements for potential improvements to the perceived progression were manifold, and various additional game elements should be considered [57]. A possibility would be to give the progression more meaning by providing game elements such as leaderboards or statistics in the end. Another possibility would be to provide more context to the progression by showing the remaining time in a well-integrated way or providing the live score to further motivate individuals. The progression model would also play a major role if the app is expanded with additional levels and other motivational aspects to further increase engagement. Such enhancements would then allow experiments with different approaches to achieve flow [50] in individuals and determine the boundaries before a level of overexcitement that impairs the instrumental value is reached.

Add Sound

Many participants stated that they wanted sound-based guidance and feedback. Using sound would be very challenging for the detection algorithm when the sounds are output through the smartphone's built-in speaker. However, this would be eliminated when using headphones. Therefore, the integration of sound-based guidance and feedback should be further investigated.

Overall Feedback

We also found that participants liked the gameful breathing training and that many participants stated by their own initiative that they preferred the gameful breathing training over the standard one. Furthermore, the participants liked that their breathing performance was reflected in the app. Combining these findings, we conclude that mobile gameful breathing training is a feasible endeavor. Nevertheless, there is still room for more game elements and improvements in Breeze, especially regarding guidance quality.

Limitations

The ultimate goal of Breeze is to increase long-term adherence. However, the results of this study do not allow us to conclude whether its current state would improve the long-term adherence relative to the standard breathing training, as it has only been used in a single session.

This study also assumes that, based on previous work, richer visualizations and game elements increased the experiential value. Although qualitative feedback indicated that an increase in experiential value was achieved for many participants, additional studies are required to substantiate this claim in the context of breathing training.

In addition, some participants felt that biofeedback helped them relax. However, this would require an additional experiment in which the measurements of 2 training sessions would be compared—1 with and 1 without biofeedback. Furthermore, the participants did not hold the smartphone in their hands, which could affect how the app is perceived and the ability to relax. However, as this was the same for Breeze and the standard breathing training, this does not limit the comparison across conditions.

Moreover, such breathing training would require an additional tutorial or onboarding phase when deployed in a nonlaboratory setting. However, a majority of the participants did not have any problems understanding the functions of Breeze after receiving a short introduction.

Finally, the fact that Breeze relies only on a smartphone makes it highly scalable. However, it should be mentioned that hardware that is specifically designed for breathing monitoring may yield more information-rich and reliable data. For example, a respiratory belt also provides information on whether the abdomen is moving correctly while breathing. This would allow more detailed feedback, but at the expense of scalability.

Future Work

With regard to the acceptance, effectiveness, and long-term adherence of breathing training such as Breeze, we plan to test it in different patient populations that require breathing training for different purposes, including, for example, students who are affected by mental health issues, want to reduce stress, or want to benefit from the general health benefits of breathing training. Other planned target populations are patients with cancer [58,59] and hypertension [60] who use breathing training as part of their complementary treatment.

We also plan to assess whether biofeedback has a beneficial effect on the efficacy of breathing training with Breeze. This can be achieved through an experiment in which breathing training is conducted with and without biofeedback.

It can be expected that in certain populations, designs other than the Breeze design would be more appealing. Thus, it is crucial to develop a design process that closely interacts with targeted populations [30]. Designing for specific target groups may lead to the necessity of partially or completely redesigning the breathing training app. In the process, we plan to consolidate and enhance the design choices of this study not only generally but also specifically to certain health outcomes. We plan to achieve this by leveraging feedback from individuals and using existing literature about designing technology to help with particular health outcomes (eg, for mental health and depression [61,62]).

Conclusions

In this study, we explained 5 design choices that guided the development of our mobile gameful breathing training Breeze. It was developed through 2 iteration cycles featuring a pretest and an evaluation in a pilot study with 16 new participants. The results yielded overall positive qualitative feedback. In addition, physiological measurements showed that Breeze can guide participants to follow a predefined breathing pattern and, in the

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process, raise their HRV and, thus, trigger health benefits. The use of Breeze reached a physiological response in participants comparable with that observed in the standard breathing training. Breeze achieved this despite the use of richer graphics and game elements, which should ultimately lead to an increased experiential value and potentially improve engagement.

Acknowledgments

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Conflicts of Interest

YL, IS, EF, and TK are affiliated with the Center for Digital Health Interventions, a joint initiative of the Department of Management, Technology, and Economics at ETH Zurich and the Institute of Technology Management at the University of St. Gallen, which is funded in part by the Swiss health insurer CSS. EF and TK are also the cofounders of Pathmate Technologies, a university spin-off company that creates and delivers digital clinical pathways. Pathmate Technologies is not involved in the study app described in this paper. All other authors have no conflicts to declare.

Multimedia Appendix 1
Breeze video.
[MP4 File (MP4 Video), 20263 KB - games_v9i1e22802_app1.mp4]

Multimedia Appendix 2
Coding table.
[DOCX File , 31 KB - games_v9i1e22802_app2.docx]

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Abbreviations

ARA: abdominal respiration amplitude
BPM: breaths per minute
HF-HRV: high-frequency heart rate variability
HR: heart rate
HRV: heart rate variability
IBI: interbeat interval
RMSSD: root mean square of the successive difference
SDNN: standard deviation of normal R-R intervals
UI: user interface
VLF-HRV: very-low-frequency heart rate variability

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Original Paper

The Effect of a Health Game Prompt on Self-efficacy: Online Between-Subjects Experimental Survey

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Related Article:

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Abstract

Background: Games for health are increasingly used as (part of) health interventions and more effect research into games for health is being done. This online experiment questions expectancies of games for health by investigating whether a game for health prompt might be considered arousal congruent cognitive reappraisal and as such positively effects self-efficacy before gameplay.

Objective: The aim of this study experiment is to test whether a game for health prompt effects self-efficacy and other well-being measurements, as a first step into investigating if a game prompt is a form of arousal congruent cognitive reappraisal.

Methods: This study used an online, 2D, between-subjects experimental survey design with self-efficacy as the main dependent variable. Stimulus is an assignment for health-related problem solving concerning living with diabetes type II, introduced as a game (n=125) versus the same assignment introduced as a task (n=107). Measurements after prompting the game/task assignment include self-efficacy, positive and negative affect, expected difficulty, flourishing, and self-esteem.

Results: The results indicate a small negative effect from prompting the game assignment on self-efficacy, compared with prompting a task assignment. This effect is mediated by the expected difficulty of the health game/task. No differences between the game and task groups were found in affect, flourishing, or self-esteem.

Conclusions: This experiment provides no support for the notion that a game for health prompt might be seen as arousal congruent cognitive reappraisal.

(JMIR Serious Games 2021;9(1):e20209) doi:10.2196/20209

KEYWORDS

self-efficacy; games for health; serious games; arousal congruent; cognitive reappraisal; prompt; flourishing; eHealth; diabetes

Introduction

Origin

In “Get excited: Reappraising pre-performance anxiety as excitement” by Brooks [1], the concept of arousal congruent cognitive reappraisal is examined by offering someone in an anxious state a prompt that aims to change their negative affect but leaves their arousal high (Table 1). She does this through prompting participants with “I am excited” and subsequently participants performed better on the task that made them anxious, and experienced a higher sense of self-efficacy. The idea is that it is more effective to shift from negative to positive affect when you can maintain your level of arousal. This follows a new line of thinking in stress research, which suggests that stress—a state of high arousal—is not necessarily harmful; effects depends on how we interpret stress. If we think and feel positive about our high arousal, stress can be helpful to our health [2].

While reading the work of Brooks, it seemed to me that prompting a game for health is also a call to be excited amidst anxious content and I wondered if a game for health might be considered arousal congruent cognitive reappraisal? If so, this

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perspective could help to explain some of the attraction to games for health and their effects on self-efficacy.

Table 1. Excitement is a state of high arousal and positive affect. Anxiety is a state of high arousal and negative affect.

Affect	High arousal	Low arousal
Positive	Excited	Calm
Negative	Anxious	Bored

Research question: Is prompting a game for health a form of arousal congruent cognitive reappraisal?

Games for Health

Health science has been embracing gaming as a meaningful way to communicate, educate, and as a mechanism to deliver treatment [3,4]. There has been a growing interest in both serious games for health and gamified health interventions [5], especially those concerning the treatment, rehabilitation, and management of chronic disease patients [6], as these games for health have shown potential for positive impact on health-behavior change [7].

Some research on the effectiveness of serious gaming for health promotion revealed an overall increase in healthy lifestyle adoption across several health domains [4] and that gameplay may induce a positive emotional experience and help facilitate satisfaction and self-esteem [6]. Effect sizes found on behavior after playing a serious game were small and comparable to the effect sizes of other computer-delivered interventions. Such effects of serious games for health were highest on knowledge outcomes, while smaller than expected on self-efficacy outcomes. Overall, the effectiveness of a health game was found to improve when game development had a theoretical foundation in behavioral prediction and game theories [8].

In order to create a full picture of the effectiveness of games for health, broader intervention characteristics should perhaps be evaluated, such as user experience and perceived relevance [9]. Some of the research into the effectiveness of games for health investigates the process during gameplay [10,11] while other research focuses on process after gameplay [8,12]. I would argue that the perceived appeal of any game for health belongs in this list of "broader intervention characteristics" and that measurements should also be made BEFORE gameplay. In this experiment a game (or a task) is announced but not given, and all the measurements concern expectations of gameplay (or task performance) that is yet to come.

Cognitive Reappraisal

Cognitive reappraisal is a change in cognition which allows for the interpretation of an emotion-eliciting situation in such a way as to alter the emotional impact it has [13]. It is using what you think to change what you feel. Cognitive reappraisal was found to increase cortisol reactivity in both a public speaking task and a cold pressor pain task, which suggests that cognitive reappraisal might even support greater physiological reactivity to acute stress and that it may increase active coping strategies [14]. One experiment showed the simplicity of cognitive reappraisal by announcing an anxiety-inducing math test as a "challenge." This decreased the experienced threat of the test and improved math performance among both high-school and university students [15]. Cognitive reappraisal might also be an effective strategy for mitigating the effects of experiencing anxiety from health-related messages. Health-risk information can be threatening in its nature and induce defensive responses [16], and health appeals can be interpreted as threatening as they confront us with disease and our own mortality [17]. The resulting state anxiety can drain working memory capacity, decrease self-confidence, harm task performance [18], and has been linked to a lowering in self-efficacy [19]. These processes are especially pertinent in a health environment, as on the one hand health information can elicit negative emotions, while on the other hand self-efficacy is known to play a role in achieving effective health behaviors [20].

Self-efficacy

Self-efficacy is a persons' belief in their capability to perform any task [19]. We tend to interpret our physical responses and our affective state as related to our capabilities, while this need not be the case. Persons with a high sense of self-efficacy can interpret a state of arousal as a motor to action, whereas persons with a low sense of self-efficacy can interpret the same state as an obstacle to action, or even an indication to cease all efforts [1]. Research has shown that self-efficacy is an important construct in many health behaviors, and it is widely seen as an important part of creating short- and long-term changes in health-related behavior [20]. A higher sense of self-efficacy has been linked to lower physiological stress responses [21] and better adherence to medical treatment [22,23].

Playing games for health has shown to invoke positive feelings [6] and improve self-efficacy [8]. Arousal is seen as a vital part of the attraction of gaming [24] and a good game will keep you aroused and engaged throughout. These elements (positive affect and high arousal) suggest that playing games for health (anxiety-inducing context) might be a form of arousal congruent cognitive reappraisal, and I suggest that this reappraisal starts before gameplay begins at the point of announcing the game. The more difficult the announced context is expected to be, the stronger the effect of reappraisal by the game prompt should be on self-efficacy.

H1 Prompting a game for health will increase self-efficacy, when compared to prompting a task for health.

H2 Prompting a game for health will increase positive affect and decrease negative affect which will correlate with higher self-efficacy, when compared to prompting a task for health.

H3 Difficulty judgment will positively mediate the strength of the correlation between prompting a game for health and self-efficacy.

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Flourishing and Self-esteem

Besides affect, flourishing and self-esteem are also incorporated as a measure of well-being that are connected to self-efficacy. The concept of flourishing [25] is based on investigating optimal human functioning; it incorporates several constructs from the field of positive psychology [26]. In contrast to the commonly used hedonic approach of subjective well-being, flourishing is based on the *eudaimonic* approach of psychological well-being and involves some of the same constructs as self-efficacy from the mastery perspective [27]. Participants reporting a higher sense of flourishing are expected to have a higher score on self-efficacy. Higher self-esteem is also linked to higher levels of mastery and self-efficacy [28]. "Self-esteem can be defined as an evaluation of one's self-concept, which is heavily dependent on reflected appraisals, social comparisons, and self-attribution" [29]. Although global self-esteem has shown to be related to many self-evaluations, it is not always equal to any domain-specific self-evaluation [30] and the effect of self-esteem on self-efficacy in this case remains to be seen. Games have been shown to facilitate greater self-esteem in a health-related context [6] and in this research I am interested in finding out if this facilitation starts at the expectancy of playing a game.

> *H4 Prompting a game for health will increase flourishing and self-esteem which will correlate with higher self-efficacy, when compared to prompting a task for health.*

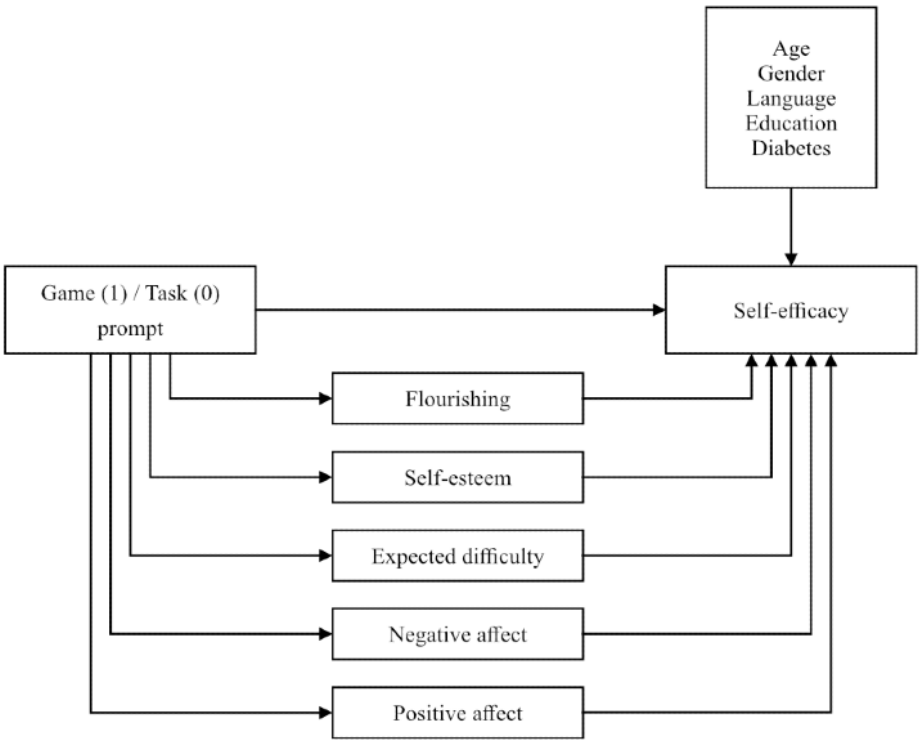
Diabetes Context

The health-related context for this experiment is that of "living with diabetes type II" which is selected as it is a prevalent lifestyle disease that is greatly impacted by health behavior, and health professionals have been especially interested in video games as a way to deliver diabetes self-management support [31-33]. Diabetes research has identified self-efficacy regarding self-care as a pivotal psychosocial variable, showing correlations of self-efficacy scores with self-care behaviors in diet, exercise, and blood glucose testing [20]. Some studies involving the effect of games for health have specifically measured the effect of a game on self-efficacy as well as behavior. One famous study investigated the effects of *Packy and Marlon* [34], which is a video game for children with diabetes where the main characters must manage their insulin levels and food intake while protecting other game characters from a rat infestation at a summer camp. After playing *Packy and Marlon* for 6 months, players not only displayed more knowledge of diabetes and its treatment, but they also displayed greater self-efficacy in management of the disease and showed improvement in diabetic-related health behavior [35]. A more recent paper described 14 different diabetes self-management games that often simulate problem solving of trying to balance food, insulin, and blood glucose. Although most games do not provide clinical validation, they are shown to improve behaviors that support diabetes self-management and will lead to better health outcomes [31].

Model of Expected Relation Between Variables

As you can see in Figure 1, I expect that participants prompted by a game for health will have higher scores on self-efficacy (H1). I also expect that positive and negative affect (H2) expected difficulty (H3), and both flourishing and self-esteem (H4) will all partially mediate the effect of a game prompt on self-efficacy. Demographic information such as age, gender, education, English as first language, and familiarity with diabetes is expected to correlate with self-efficacy, but not with receiving a game or task prompt.

Figure 1. Hypothesized relationships.



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Methods

Study Design

This is an online, 2D, between-subjects experimental design with self-efficacy as the main dependent variable.

Stimulus

The stimulus material contains references that are both health related and math related, in an attempt to increase a sense of difficulty. The opening page of the survey displayed the blue logo of the Diabetes Foundation and 2 blue snakes around a blue staff, a visual that is generally associated with the medical profession. On this page participants were confronted with a text asking them to solve issues related to living with diabetes type II. The text tells them that they will have to solve these unknown problems in either a *game* or in a *task* environment:

> *Thank you for participating in this research, it will take approximately 5-10 minutes. All your answers will be stored and analysed anonymously.*
>
> *HEALTH GAME [TASK] On the next pages you will be asked to play a game [task] in which you have to solve several health related problems concerning living with Diabetes type II. This game [task] includes dealing with glycaemic control, caloric intake, measurement intervals and other issues. The game [task] requires no specific prior knowledge and you do not need to have Diabetes to participate.*

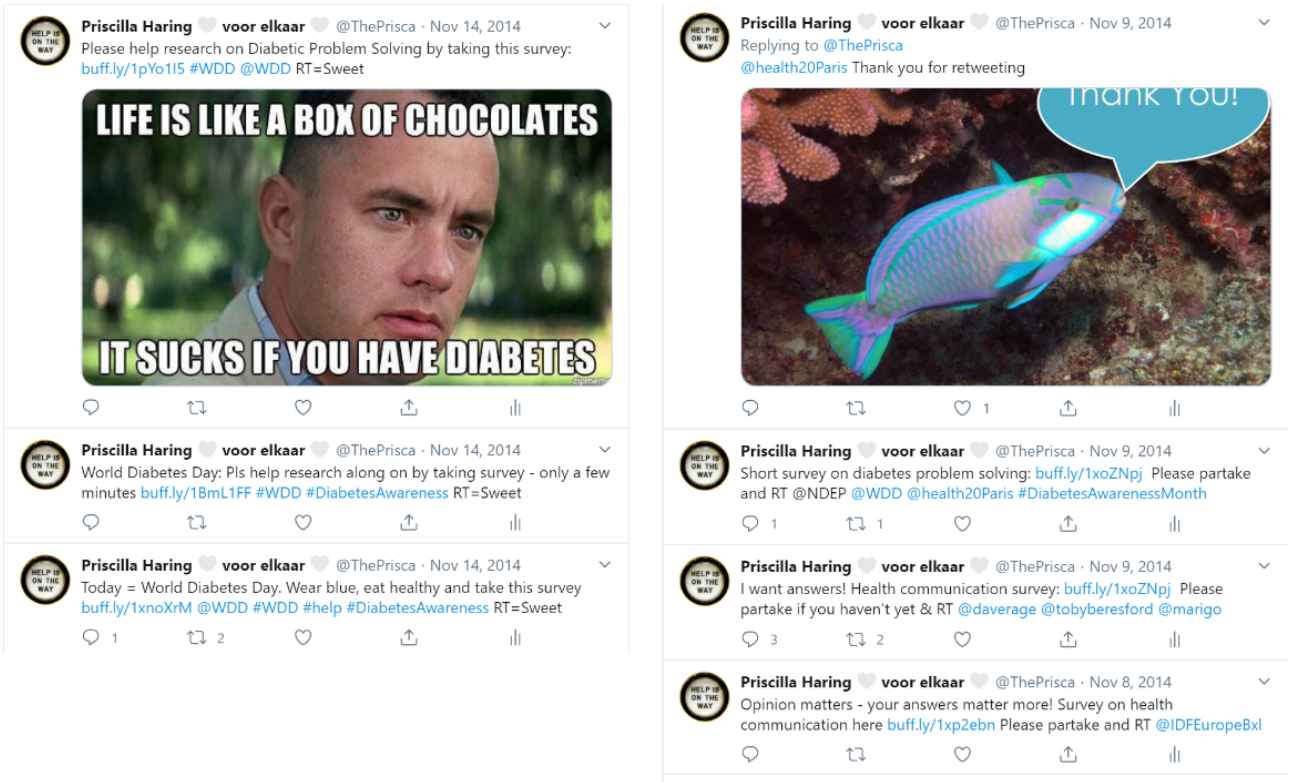
After reading the text, the survey begins on the next page. Throughout the survey the words “game” or “task” are repeated 12 times. A manipulation check is included after the measurements, asking the participants if they are about to play a game or perform a task (or they don’t know). At the end of the survey a short debriefing explains the purpose of the experiment.

Participants

To establish the necessary number of participants, a power calculation was performed with G*Power [36]. A 2-tailed, a priori power calculation for *t* test mean difference between 2 independent groups was done, with the expected effect size of the dependent variable based on “[…] participants in the “get excited” condition reported higher self-efficacy by comparison (mean 5.66 [SD 1.01], t=–2.35, P=.021; d=.415)” [1]. This power calculation indicated that 186 or more participants would be sufficient to detect the expected effect of d=0.415 with a power of $(1–\beta)=0.8$ and $\alpha=.05$, when N=186 is equally distributed over the 2 independent groups. Random and even distribution of participants into either the game or task group was managed by Qualtrics, the software used for the survey design and online data collection [37].

The experiment was hosted online for 2 weeks during the Diabetes Awareness Month. A post on my social media accounts invited people to participate in “research on health-related choices” and encouraged sharing a link to the research with others. Participants were also recruited by specifically targeting Twitter accounts that were game and diabetes related (Figure 2). There were no entry criteria and no consequences to participating.

Figure 2. Recruiting participants on Twitter.



In a second round participants were hired on the micro-task market: Amazon’s Mechanical Turk. Such Mechanical Turks are best used in cases where there is a small task with a need for many users, when there is a verifiable answer, and there are

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no objections to a diverse and unknown group of participants [38]. To encourage accurate answers, I included an announcement before the survey started that a check (the manipulation check) was included in the survey, and that there would be no pay-out if this check was missed or wrong. These MTurks were paid the equivalent of 8 minutes' work under Dutch adult minimum wage. Eventually, 78 participants in the data set (33.6%) originated from online snowballing and 154 (66.4%) were recruited as MTurks (N=232).

Participants that passed the manipulation check and had no missing values were included in the analysis. In total, 232 participants were included in analysis (115 men and 117 women; average age 37.5 years, 125 game group and 107 task group). No significant differences were found between the game and task group on the variables gender, age, education level, or experience of diabetes.

Measurements

The survey consisted of 4 screens. The first screen contained the introduction and the stimulus, the second contained the self-efficacy and expected difficulty measurement. The third screen contained demographic, flourishing, Positive and Negative Affect Schedule (PANAS), self-esteem, experience of diabetes measurement, and the manipulation check. The fourth and last screen contained the debriefing and a comment/question box, followed by my thanks, my name, and academic title.

Self-efficacy

In this experiment self-efficacy is measured by adapting 2 established measures: the 13-item reduced form Coping Self-Efficacy Scale (CSES) [39] and the State Self-Efficacy Subscale (SSESS) [40]. The base question for the CSES was adapted to the context of the experiment:

"Before we start - We want to ask you to give a confidence rating on the game you are about to do. How confident or certain are you that you can do the following things in the game on Living with Diabetes type II". This phrasing is in line with the 'Guide for constructing self-efficacy scales' [41].

This experiment uses 2 CSES subscales: Problem-Focused Coping (PFC; 6 items, α=.90) and Stop Unpleasant Emotions and Thoughts (SUET; 4 items; α=.90).

Items of the CSE subscale PFC include the following:

- Break an upsetting problem down into smaller parts
- Sort out what can be changed, and what cannot be changed
- Make a plan of action and follow it when confronted with a problem
- Leave options open when things get stressful
- Think about one part of the problem at a time
- Find solutions to your most difficult problems

Items of the CSE subscale SUET include the following:

- Make unpleasant thoughts go away
- Take your mind off unpleasant thoughts
- Stop yourself from being upset by unpleasant thoughts
- Keep from feeling sad

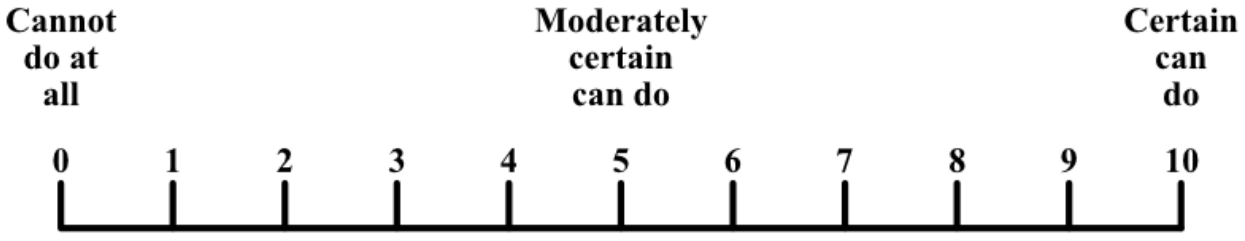
For this experiment, the wording of the items from the SSESS was adapted from the evaluative form into an expectant form. Furthermore, 2 items based purely on self-efficacy of content knowledge were deleted, leaving 4 items (α=.94).

Items of the adapted SSESS include the following:

- In the GAME/TASK, I expect to do well
- I have no doubts about my capability to do well on this GAME/TASK
- I am sure I can do an excellent job in this GAME/TASK
- Even when the GAME/TASK questions are difficult, I know I can succeed

All 14 self-efficacy items are combined in 1 matrix (α=.95). Performing a principal component factor analysis on the full matrix of 14 items revealed 1 underlying component. All answers were given on a 0-10 range with 3 semantic anchors (Figure 3), the same answer format that is used in the CSES.

Figure 3. Self-efficacy answer format.



Positive and Negative Affect

In order to measure emotional valence, the PANAS is used [42]. When Kobau and colleagues [43] researched the most used measurements of well-being as related to health, they found an interitem consistency of α=.91 for the Positive Affect Subscale and α=.86 for the Negative Affect Subscale.

Flourishing

Another measure of well-being is taken with the 8-item Flourishing Scale [26] with answers given on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). This relatively new scale was also used as part of the New Zealand's Sovereign Well-Being Index (N=100,009) [44]. Subsequent analyses of the underlying structures and psychometric properties of the scales were performed as well as reliability and validity checks and benchmarking to other well-being scales

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used in the survey. The study concluded that the flourishing scale "is a valid and reliable brief summary measure of psychological functioning, suited for use with a wide range of age groups and applications " [44]. In the data from this experiment, the flourishing scale (α=.90, mean 4.07 [SD 0.65]) correlates with other measurements of well-being (PANAS and self-esteem) as expected.

Expected Difficulty

The expected difficulty of the game or task is measured in 1 item by asking the participants how difficult they expect the task/game is going to be and assessing this on a 7-point scale with 2 semantic anchors (1=very easy, 7=very difficult). This measure is an adaptation of the After-Scenario Questionnaire [45].

Self-esteem

Self-esteem is measured by a Single-Item Self-Esteem (SISE) Scale. The SISE was banked against the Rosenberg Self-Esteem Scale [46] along with other measures of domain-specific self-evaluation, personality, well-being, and behavioral measures and was found to give a reliable measure of self-esteem for adults [30].

Diabetes Experience

Participants were asked how familiar they were with diabetes and its challenges, choosing between 4 possible answers:

- I have Diabetes
- Someone close to me has Diabetes
- I have no personal experience of Diabetes but I am aware of what Diabetes is and what the challenges are
- I have no or very limited knowledge on this subject

Demographics

Participants were also asked about their gender, level of education, year of birth, and if their native language was English or otherwise.

Results

Overview

The research question investigates the idea that prompting a game to solve health-related problems might be a form of arousal congruent cognitive reappraisal, similar to the "get excited" prompt [1] and as such would result in increased self-efficacy. In order to start exploring this question, a number of hypotheses were formed and tested. If the announcement of a game for health is arousal congruent cognitive reappraisal, participants that are prompted by such a game for health are expected to have higher scores on self-efficacy (H1) while positive and negative affect (H2), expected difficulty (H3), and both flourishing and self-esteem (H4) will all partially mediate the effect of a game prompt on self-efficacy, compared with participants that are prompted by a task for health.

Correlations of Measurements

Looking at the participants in either the game or task group in Table 2, there is a small, negative correlation between self-efficacy and belonging to the game or task group (r=–.17, P<.01) (H1) as well as a small, negative correlation between belonging to the game or task group and difficulty judgment (r=–.15, P<.05) (H4). However, no other significant correlations are found. Self-efficacy scores also correlate significantly with positive affect (r=.49, P<.01) and negative affect (r=–.35, P<.01) (H2), difficulty judgment (r=.40, P<.01) (H3), flourishing (r=.54, P<.01), and self-esteem (r=.41, P<.01) (H4).

Further negative correlations with self-efficacy scores are shown with diabetes knowledge (r=–.22, P=.001) and being an English native speaker (r=–.13, P=.04), while a positive correlation is being shown with being recruited as an MTurk (r=.29, P=.001) versus via snowballing.

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Table 2. Correlation table.

Correlation	Positive affect	Negative affect	Self-efficacy	Difficulty judgment	Flourishing	Self-esteem	Diabetes experience	Education	Gender	Age	Language	MTurk
Game (1)/Task(0)	–.100	.007	–.170[b,c]	–.150[a,b]	–.125	–.044	.087	–.035	–.070	.007	.020	–.091
Positive affect	—	–.143[a,b]	.494[b,c]	.365[b,c]	.594[b,c]	.522[b,c]	–.236[b,c]	.155[a,b]	–.068	–.001	–.046	.312[b,c]
Negative affect		—	–.346[b,c]	.074	–.385[b,c]	–.155[a,b]	.003	.015	–.052	–.221[b,c]	.116	.004
Self-efficacy			—	.404[b,c]	.543[b,c]	.411[b,c]	–.224[b,c]	.035	.007	.000	–.133[a,b]	.289[b,c]
Difficulty judgment				—	.303[b,c]	.390[b,c]	.200[b,c]	.083	–.108	–.195[b,c]	.003	.340[b,c]
Flourishing					—	.569[b,c]	–.183[b,c]	.138[a,b]	.088	–.020	–.080	.142[a,b]
Self-esteem						—	–.189[b,c]	.191[b,c]	–.099	–.045	–.130[a,b]	.296[a,b]
Diabetes knowledge							—	.102	.055	–.224[b,c]	.325[b,c]	–.325[a,b]
Education								—	–.014	–.148[a,b]	.266[b,c]	–.113
Gender									—	.043	.038	–.122
Age										—	–.114	–.095
Language											—	–.391[b,c]

[a]*P*<.05 (2-tailed), N=232.

[b]Significant value.

[c]*P*<.01 (2-tailed).

Direct Effect of Belonging to the Game or Task Group on Self-efficacy

To investigate the effect of prompting a game or task for health on self-efficacy (H1), a comparison was made of the average compound self-efficacy score (14 items) of the game versus the task group via independent samples *t* test. This analysis revealed a difference in self-efficacy scores (t_{230}=2.62, *P*≤.01) between the game group (mean 8.08 [SD 1.75]) and the task group (mean 8.66 [SD 1.61]) in the direction opposite to expectations, showing a small but significant (*P*≤.01) higher sense of self-efficacy in the task group. Performing the same *t* test on standardized self-efficacy scores reveals a small to medium effect size of *d*=3.41.

To investigate the relation between belonging to the game or task group and self-efficacy further, the average scores on these (sub)scales between the game or task group were tested simultaneously by a one-way between-subject ANOVA. For the SSESS significant differences between the game group (mean 8.12 [SD 2.21]) and the task group (mean 8.97 [SD 1.72]) were found, with the Levene test showing that the variances of these scores were not equal ($F_{1,230}$=10.91, *P*=.001). Participants also scored differently on the subscale CSE-PFC in the game group (mean 9.77 [SD 2.11]) versus the task group (mean 10.45 [SD 1.92]; $F_{1,230}$=6.58, *P*<.05). However, on the subscale CSE-SUET between the game group (mean 7.94 [SD 2.14]) and the task group (mean 8.27 [SD 2.01]) no significant differences could be found ($F_{1,230}$=1.50, *P*=.22).

Direct Effect of Belonging to a Game or Task Group on Affect

To investigate if the game group will have a lower negative affect and a higher positive affect when compared with the task group (H2), an independent sample *t* test was performed to compare average affect scores between groups. The scores on positive affect in the game group (mean 3.54 [SD 0.81]) and the task group (mean 3.69 [SD 0.70]) showed no significant difference (t_{230}=1.53, *P*>.1). The scores on negative affect in the game (mean 1.83 [SD 0.78]) and task groups (mean 1.82 [SD 0.82]) also were not significantly different (t_{230}=–0.10, *P*=.92).

Effect of Difficulty Judgment on the Relation between the Game or Task Group and Self-efficacy

Investigating the subset of participants that answered Somewhat difficult, Difficult, or Very Difficult (n=79), a difference on the average self-efficacy score (H3) between the game (mean 7.00 [SD 2.38]) and task (mean 8.52 [SD 2.16]) prompted group was found, but this was not significant (t_{77}=1.72, *P*>.05).

Direct Effect of Belonging to the Game or Task Group on Flourishing and Self-esteem

To investigate if belonging to the game group has a positive effect on flourishing (H4), an independent sample *t* test was performed to compare average flourishing scores between the game and task groups. The scores on flourishing in the game group (mean 4.00 [SD 0.58]) and the task group (mean 4.16

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[SD 0.69]) showed no significant difference (t_{230}=1.91, P=.58). Comparing the average self-esteem scores (H4) between the game group (mean 3.79 [SD 1.02]) and the task group (mean 3.87 [SD 0.95]) also showed no significant differences (t_{230}=.67, P=.51).

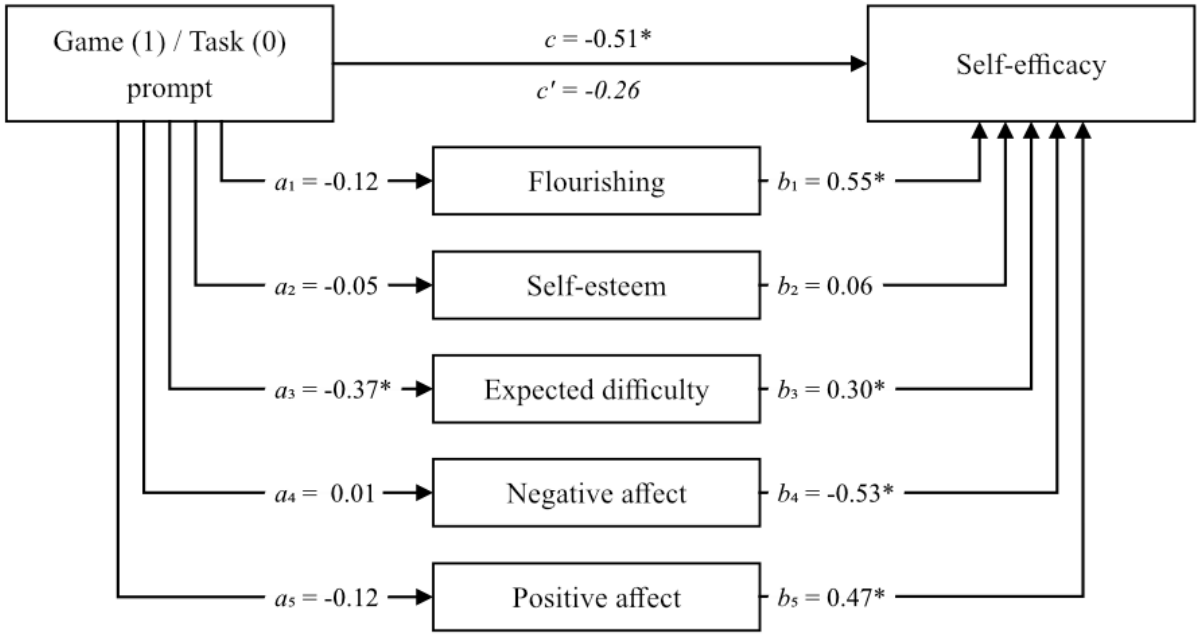
Demographics and Diabetes Experience

No significant differences were found between participants in the game or task group on age (t_{230}=–0.11, P=.92), gender (t_{230}=1.06, P=.29), language (t_{230}=–0.30, P=.77), education level (t_{230}=0.53, P=.60), or experience of diabetes (t_{230}=–1.32, P=.19).

Mediation Model Test

In order to test the conceptual model as a whole, a mediation analysis was conducted using the PROCESS macro (model 4: 10,000 bootstrap samples). This model is used for both simple mediation models and parallel multiple mediator models [47]. The effect of belonging to the task or game prompt group on self-efficacy was tested, while including positive and negative affect, difficulty judgment, self-esteem, and flourishing as possible mediators and adding diabetes knowledge, first language, age, education, and gender as covariates. The results are shown in Figure 4.

Figure 4. Mediation model. Multiple mediator model with flourishing, self-esteem, expected difficulty, and both negative and positive affect as mediators on the effect of a game or task prompt on self-efficacy. Age, gender, language, education, and diabetes experience are included as covariates (paths not shown). *P<.05.



This analysis shows that the direct effect path between a game and a task prompt on self-efficacy is significant (c=–0.51, 95% CI –0.94 to –0.07), but this effect loses strength and its significance when the mediators are taken into account (c'=–0.26, 95% CI –0.61 to 0.08). In the model expected difficulty was shown to be a mediator, as both the path from game or task prompt to expected difficulty (a_3=–0.37, 95% CI –0.71 to –0.02) and the path from expected difficulty to self-efficacy (b_3=0.30, 95% CI 0.16 to 0.45) were significant. For flourishing (b_1=0.55, 95% CI 0.16-0.94) as well as negative affect (b_4=0.53, 95% CI –0.77 to –0.29) and positive affect (b_5=0.47, 95% CI 0.18-0.77) only the second paths in the model show a significant effect, indicating that these might be moderating but not mediating the relationship between the game or task prompting and self-efficacy. Self-esteem on both paths (a_2=0.05, 95% CI –0.29 to 0.20 and b_2=0.06, 95% CI –0.17 to 0.29) shows no effects of significance in this model.

Further testing of flourishing and positive and negative affect as moderators between game or task prompting and self-efficacy (including the same covariates as in the mediation model) did not result in any significant paths, and discounted these variables as moderators.

MTurks or Snowballing

Average scores on several variables between the 2 differently recruited groups were compared and tested via independent t tests. MTurk participants showed a higher score on the self-efficacy measure (t_{230}=4.582, P≤.001, d=0.61) when compared with the participants that were recruited via snowballing. MTurk participants expected the task/game to be less difficult (t_{230}=5.486, P≤.001), in comparison to the snowballing group. The group of MTurks also scored significantly higher on flourishing (t_{230}=2.172, P≤.05), the positive part of the PANAS (t_{230}=4.974, P≤.001), self-esteem (t_{230}=4.696, P≤.001), and indicated more experience of diabetes (t_{230}=–5.026, P≤.001).

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Data

The anonymized data set "The Effect of a Game Prompt on Self-Efficacy Concerning Problem-Solving Challenges of Living with Diabetes type II" can be found online at the Open Science Framework [48].

Discussion

Principal Findings

There are several significant correlations between the variables measured in this online survey. Being confronted with the game for health stimulus correlates with a little less self-efficacy and with the expected content being judged a little more difficult, compared with being confronted with the task stimulus. The scores of the flourishing scale correlate with the PANAS, self-esteem, and self-efficacy as expected, confirming these measurements of well-being among themselves within this data set.

When the relationship between self-efficacy after a game prompt or a task prompt was tested, scores in each group are significantly different. The game group scores an average of 8.08 on self-efficacy, while the task group scores on average 8.66. This scoring indicates answers between 0=cannot do at all and 11=certain can do. Even though a difference in scoring between groups is found, the difference in scores is small and the average scoring in both groups represents a high amount of self-efficacy.

A significant difference between game and task group participants holds on the State Self-Efficacy Scale and PFC Subscale, but disappears in the scores on the subscale for stopping unwanted emotions or thoughts. That no effect could be found on this subscale might be due to the limited timespan of the survey (5-10 minutes) which is likely not long enough to raise the issue of consciously controlling ones' emotional and cognitive state.

The expectation that a game for health prompt would be followed by more positive affect and less negative affect was not found. No significant difference in affect was found at all between the game and task groups. Neither could any significant difference in the scores on self-esteem or flourishing be found between the task and game groups.

When looking at the subset of participants that judged the expected content to be difficult, no significant effect of either the game or task stimulus could be found on self-efficacy. However, because many participants did not judge the expected content as difficult, this analysis relies on a smaller number (n=79) which might explain the lack of a robust finding. The results might be indicating a trend that a drop in self-efficacy following a game prompt will get bigger if the content is expected to be more difficult.

Through running a mediation analysis it becomes clear that the difficulty judgment fully mediates the connection between participating in the game prompt or task prompt group and the score of self-efficacy. This mediation indicates that a game for health prompt creates the expectancy of slightly more difficult content compared with the task prompt, which influences the relationship between the type of prompt and self-efficacy in the direction of a game prompt being followed by a little less self-efficacy.

No differences were found between the game and task group in flourishing and self-esteem average scores. Although negative and positive affect as well as flourishing show a significant relation to self-efficacy scores in the mediation model, neither mediation nor moderation can be established and not much can be said on the connection between these variables from these data.

The use of MTurks for online surveys and experiments is getting more widespread [49]. However, this experiment shows that how participants are recruited can have its own effect on outcomes. On all the self-evaluative measures in this experiment, MTurks scored different from the snowball participants. How participants were recruited showed a greater effect on self-efficacy (d=.61), the main dependent variable in this study, than the effect of the manipulation (d=.34).

Limitations

This experiment has no heart rate measure as an indication of arousal, which is a practical limitation of doing online research. Subjective measures of arousal do exist (such as a self-report scale that might be used online), but research indicates that such measures did not match physiological data collected via electromyography and skin conductance [50] and as such do not provide valid measurements.

Although mediating effects are found from difficulty judgments, participants on average expected this assignment to be "neutral," meaning neither difficult nor easy. Future research might investigate game or task prompting where the judgment of the expected content is on the "very difficult" side of the scale.

No measurement of game literacy is included in the study; this information might provide interesting correlations with expectations of playing games for health. Future research might look at the level of experience with 3 game categories: entertainment games, serious gaming, and games for health. A further investigation of lay-beliefs and expectancies of these 3 categories before any gameplay seems warranted.

Conclusions

The aim of this study was to try and establish a first foothold into investigating whether prompting a game for health might be considered arousal congruent cognitive reappraisal. As far as this one small study can indicate anything, it appears to indicate that this is not the case. Games or gamification in health care context have been shown to increase self-efficacy [6]. However, this positive process does not seem to start at the moment of announcing a game.

Prompting health-related content as a game is followed by slightly less self-efficacy (H1), mediated by an increase of the expected difficulty (H3) between "neutral" and "somewhat difficult," when compared with the assignment as a task. This could be interpreted as the view that games are expected to be more challenging in a negative way. Those who wish to use gaming or gamification for diabetes type II–related

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interventions, or more broadly in a health-related setting, should be aware of this.

There is no difference in affective state found following a game or a task prompt (H2) and no difference is found between the game and task groups in flourishing and self-esteem (H4). Together, this provides no support for the notion that a game prompt might be seen as cognitive reappraisal.

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Conflicts of Interest

None declared.

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Abbreviations

CSES: Coping Self-Efficacy Scale
PANAS: Positive and Negative Affect Schedule
PFC: Problem-Focused Coping
SISE: Single-Item Self-Esteem
SSESS: State Self-Efficacy Subscale
SUET: Stop Unpleasant Emotions and Thoughts

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Original Paper

Exergaming Platform for Older Adults Residing in Long-Term Care Homes: User-Centered Design, Development, and Usability Study

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Abstract

Background: Older adults (OAs) residing in long-term care (LTC) homes are often unable to engage in adequate amounts of physical activity because of multiple comorbidities, including frailty and severe cognitive impairments. This level of physical inactivity is associated with declines in cognitive and functional abilities and can be further compounded by social isolation. Exergaming, defined as a combination of exercise and gaming, has the potential to engage OAs in exercise and encourage social interaction. However, previously used systems such as the Nintendo Wii are no longer commercially available, and the physical design of other exergames is not suitable for OAs (ie, fall risks, accessibility issues, and games geared toward a younger population) with diverse physical and cognitive impairments.

Objective: This study aims to design and develop a novel, user-centered, evidence-based exergaming system for use among OAs in LTC homes. In addition, we aim to identify facilitators and barriers to the implementation of our exergaming intervention, the MouvMat, into LTC homes according to staff input.

Methods: This study used a user-centered design (UCD) process that consisted of 4 rounds of usability testing. The exergame was developed and finalized based on existing evidence, end user and stakeholder input, and user testing. Semistructured interviews and standardized and validated scales were used iteratively to evaluate the acceptability, usability, and physical activity enjoyment of the MouvMat.

Results: A total of 28 participants, 13 LTC residents, and 15 staff and family members participated in the UCD process for over 18 months to design and develop the novel exergaming intervention, the MouvMat. The iterative use of validated scales (System Usability Scale, 8-item Physical Activity Enjoyment Scale, and modified Treatment Evaluation Inventory) indicated an upward trend in the acceptability, usability, and enjoyment scores of MouvMat over 4 rounds of usability testing, suggesting that identified areas for refinement and improvement were appropriately addressed by the team. A qualitative analysis of semistructured interview data found that residents enjoyed engaging with the prototype and appreciated the opportunity to increase their PA. In addition, staff and stakeholders were drawn to MouvMat's ability to increase residents' autonomous PA. The intended and perceived benefits of MouvMat use, that is, improved physical and cognitive health, were the most common facilitators of its use identified by study participants.

Conclusions: This study was successful in applying UCD to collaborate with LTC residents, despite the high number of physical and sensory impairments that this population experiences. By following a UCD process, an exergaming intervention that meets

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diverse requirements (ie, hardware design features and motivation) and considers environmental barriers and residents' physical and cognitive needs was developed. The effectiveness of MouvMat in improving physical and cognitive abilities should be explored in future multisite randomized controlled trials.

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KEYWORDS

user-centered design; aged; long-term care; nursing homes

Introduction

Background

Globally, 3%-5% of the 962 million older adults (OAs) [1] live in some form of long-term care (LTC) home to receive assistance with their activities of daily living and primary medical care [2]. There is significant growth in the demand for LTC in almost every country; for instance, Canada's demand for LTC is twice that of its current capacity [3]. Routine physical activity (PA) is a widely recognized component of healthy aging among OAs [4-6]. However, it is difficult for OAs who reside in LTC homes (herein referred to as residents) to engage in adequate amounts of PA because of multiple comorbidities, including frailty and severe cognitive impairments [1,7]. The sedentary nature of living in LTC homes is well documented [8], and this level of physical inactivity significantly increases the likelihood of further declines in cognitive and functional abilities, especially in the first few months after OAs are admitted to LTC homes [9]. The high prevalence of physical and cognitive impairments among LTC residents also compounds social isolation [10,11], a risk factor that negatively influences cognitive [12] and mental health.

The World Health Organization [13] reports a critical need for interventions that can help OAs maintain their physical and cognitive health and reduce social isolation. Given the globally aging population and increased pressure on international LTC sectors, there is a need for effective, translatable, and sustainable interventions that can provide opportunities for physical, cognitive, and social stimulation to LTC residents. Exergaming products are a safe way to improve these outcomes in OAs [14-17]. The current literature suggests that exergames have positive social, cognitive, and physical effects [18-21]. Exergaming technology is described as interactive exercise-based games, whereby players are able to engage in physical and cognitive activities through a game. Exergaming provides an enjoyable means to motivate LTC residents and offers opportunities to use both motor and cognitive skills. The mechanism of this benefit is supported by the cognitive enrichment hypothesis [22], which states that the collective behaviors of an individual have a meaningful positive impact on cognition and function in old age. Thus, exergaming may exert its positive effects by providing simultaneous physical, cognitive, and social stimulation, which in turn mitigates functional decline.

However, an ongoing analysis of the existing body of evidence regarding the validity of exergaming as an activity for OAs has revealed that many studies are outdated [23] and are predominantly based on gaming systems that are no longer commercially available, such as the Nintendo Wii or the XBOX Kinect [24]. These popular systems were not designed for residents in institutional settings, such as LTC homes, and therefore have several features that make them less suitable for this population. First, interactive gaming platforms that encourage movement, such as Nintendo Wii Yoga and Dance Dance Revolution, use raised platforms or metal pads and mats posing a fall risk and accessibility issues for residents with physical disabilities or who require wheelchairs [19]. Although these gaming systems are accessible for research purposes, the physical design poses safety hazards for residents [25]. Second, the multiple small components, such as handheld controllers, are also difficult to sanitize, posing a risk to infection control. Third, the games offered are generally designed around the interests of younger populations and often encompass small text, fast flashing screens with visual distraction, and unrelatable game concepts that are more difficult for OAs to comprehend (eg, collecting imaginary characters) [26]. In addition to the gaming system limitations of previous work, from a methodological perspective, there are only a small number of exergaming studies that included residents with cognitive impairment [18], despite 87% of residents living with some type of cognitive impairment [27]. Furthermore, we were unable to find studies that aimed to co-create an interactive exergaming platform for LTC residents from ideation to validation and implementation in LTC homes. These methodological shortcomings not only point to a discrepancy between the state of the evidence and the advanced needs of residents and the LTC environment, but also underscore the urgent need for gaming systems that are applicable to this population in their congregate home settings.

In response, we used a design science research strategy to develop an exergaming platform that can promote the increased general PA, cognitive stimulation, and social engagement of residents in LTC homes. We applied a user-centered, iterative design process [28,29] to center the experiences and perspectives of residents and other stakeholders to address the safety, accessibility, and practical disadvantages of existing systems. The vision was to create an exergaming platform that was versatile and fully adaptable to meet the range of physical abilities of LTC residents (eg, able to encourage lower body activity in residents who are able to ambulate with or without a gait aid or engage the upper body of residents who are in wheelchairs or unable to ambulate) and meet the diverse social needs of residents in LTC (ie, ability to play single-player or multiplayer games). The platform software should be customizable with respect to difficulty levels, and the hardware should have the capability to be physically reconfigured to meet the needs of the participants.

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Objectives

The first aim of this paper is to describe the iterative process of developing a prototype of a novel exergaming system, the MouvMat, designed for residents with varying cognitive and physical abilities to improve its acceptability, usability, and enjoyment to residents and stakeholders, including staff and family members. The second aim is to identify the facilitators and barriers to the implementation of the MouvMat in LTC homes according to staff stakeholders.

Methods

Study Enrollment

Following internal alpha testing, our research team collaborated with 2 LTC homes located in Toronto, Ontario, Canada, to recruit the study participants. Various recruitment strategies included posters and direct enrollment by an LTC home staff collaborator. If available, participants were invited to participate again for each of the 4 rounds of usability testing. Study inclusion criteria for residents were as follows: participants should (1) be a resident of an LTC home; (2) be aged ≥65 years; (3) be able to read, speak, and write in English; and have a score above 10 on the Mini-Mental Status Examination (MMSE) [30]. Collaterals were eligible if they were (1) a family member, substitute decision maker (SDM), or personally hired caregiver of an OA living in an LTC facility; (2) able to read, speak, and write in English; and (3) aged ≥18 years. LTC home staff were eligible if they were able to communicate in English and were currently working in an LTC facility. Study eligibility was assessed as part of the informed consent form. Once enrolled, a research assistant collected demographic information and familiarity with electronic devices and game technologies, administered the MMSE [31], and completed the Frailty in Nursing Homes Scale (FRAIL-NH) [32], with the latter two measures administered to residents only. Frailty (ie, FRAIL-NH), cognitive status (ie, MMSE), and presence of sensory or motor impairments were collected to ensure and demonstrate that MouvMat was accessible to LTC residents with varying cognitive and physical abilities.

User-Centered Design Process

A robust 3-phase user-centered design (UCD) process was applied [28,29]. The first phase of the exergaming platform design was based on developing an explicit understanding of residents and LTC home environments with residents and LTC staff. Interviews, a SWOT (strengths, weaknesses, opportunities, and threats) analysis, and paper mock-ups were completed in line with ISO 9241-210:2019 (human-centered design standards) [29] that have been described elsewhere [33]. Potential end users, including residents in LTC and LTC staff and health care providers, were involved in all steps of prototype conceptualization and development. The second phase included creating a testable prototype of the exergaming platform and gathering feedback from stakeholders and end users using a think-aloud method [34] to assess the acceptability of the idea and to inform the development of a high-fidelity prototype [35,36].

Finally, the third phase was focused on conducting 4 rounds of usability testing of the high-fidelity prototype with one or more games (game descriptions are provided in Multimedia Appendix 1) and conducting summative user feedback with each iteration of the exergame. Participants enrolled in the study (residents, family members or SDM, and staff) were invited to complete 1-hour user testing sessions that involved using the prototype with a concurrent think-aloud method. Each of the 4 user testing sessions followed the same sequence and involved (1) informed consent and collection of demographic and characteristic information, as well as cognitive and frailty measures (MMSE and FRAIL-NH); (2) engagement with the prototype using the talk-aloud method; (3) quantitative measures; and (4) a semistructured interview informed by an interview guide.

To start the user testing session, a safety checklist was first filled out by a team member to mitigate fall risk during testing. Each user testing session was supervised by at least one researcher and game designer or engineer who were also present to take notes on system functionality and usability. The checklist comprised 5 questions, each answered with either yes or no responses to (1) confirm whether the participant was wearing nonslip footwear, glasses, and hearing aids, if needed, and whether the participant was not feeling tired or drowsy and (2) ensure that the testing environment was distraction free and quiet before reading the instruction script. Distractions and background noise can make the instructions difficult to hear, which may cause confusion, so it was important to verify that the participant and the testing conditions were safe before proceeding with the testing. If any condition was not met, a research team member would contact the staff or the testing session would be rescheduled to another time.

During the testing, team members observed and documented the ergonomic navigation of participants and the emotional responses of participants while engaging with the exergame. Functionality and participant performance (ie, the number of games played, number of levels completed, and number of errors) were documented during each session. In addition, behavioral observations and participant comments from the think-aloud method during the use of the MouvMat were recorded [37]. Observations are a central activity in UCD because they provide insights into how OAs were physically navigating on and around the MouvMat and how they interacted with the technology, for example, their facial or verbal expressions when they heard audio sounds, saw blinking lights, or successfully completed a level. Each participant was closely observed by multiple team members to ensure that small cues were not missed and each team member documented their own observations, which were later discussed as a group. During interaction with the prototype and talk-aloud responses, researchers avoided providing feedback or extensive comments to participants so as to minimally affect their potential responses to subsequent measures. Participants who were nonweightbearing or immobile in a wheelchair were provided a handheld device to point and tap on the system, whereas those who were mobile were able to stand up and tap the system with their foot. LTC residents' sessions were completed individually or with a family member, SDM or caregiver present if this was their preference or if required.

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Each user testing session was concluded with a semistructured interview focused on 6 constructs (functionality, usability, accessibility, enjoyment, acceptability, and design) to gather feedback about the game, hardware, and interface and to enhance our understanding of those concepts (usability, acceptability, and enjoyment) that were also measured with standardized and validated tools. The interviews were audio recorded, transcribed, and analyzed using thematic analysis [38] after each round. The research team would discuss the participants' feedback, themes, and redesign the prototype to make appropriate changes that would better meet user needs in subsequent rounds of usability testing. If there were behaviors noted during the observation, the participant was asked to clarify or explain during the interview. For example, if the resident laughed when playing the game, they would be asked what specifically triggered their laughter, or if they asked a question about the game while playing, we inquired about the specific aspect they found confusing. Each participant received an honorarium for the time following the completion of the study. This iterative process was completed in 4 separate iterative rounds between July 2018 and December 2019 (approximately 18 months). The University of Toronto Research Ethics Board (RIS#37453) approved the study.

Outcome Measures

In total, 3 main standardized and validated scales were used to evaluate the acceptability, usability, and PA enjoyment of the MouvMat. Acceptability refers to the values, judgments, and beliefs about the effectiveness, risks and benefits, and perceived usability of a treatment or innovation and is a primary determinant of end user uptake [39]. An adapted modified Treatment Evaluation Inventory (m-TEI) [40,41] was used to assess the acceptability of residents and stakeholders (ie, collaterals and staff). Stakeholders play a critical role in LTC, and their perceptions can either positively or negatively influence residents' engagement with interventions [39]. Next, the System Usability Scale (SUS) [42,43] was used to evaluate the subjective usability of newly developed devices and systems. The SUS is a widely used validated and reliable scale consisting of 10 items and a score ranging from 0 to 100, with 68 representing the minimally acceptable usability score. Third, the 8-item Physical Activity Enjoyment Scale (PACES-8) [44] is a brief measure of subjective enjoyment of physical exercise validated in OAs [44]. Enjoyment is a relevant measure because it is both an important predictor and outcome of PA participation in OAs [45]. Furthermore, OAs' anticipated enjoyment from physical activities can predict their adoption of and motivation to engage in physical activities [46,47].

Data Analysis

Participant demographics were summarized using descriptive statistics. Questionnaire scores from m-TEI, SUS, and PACES-8 were compared across the four usability testing sessions and between participant groups (ie, residents, family members, and staff). We tested for differences across groups and testing sessions using linear mixed models fit by maximum likelihood, which allows for the analysis of repeated, longitudinal assessments in which there are cases of missing data [48]. Analyses were run in the GAMLj module of Jamovi software [49], and the model for each outcome measure included a random intercept for participants, with fixed effects for group (residents, family members, and staff or administrators) and usability testing sessions.

A qualitative content analysis approach [50] of the transcribed semistructured interviews was undertaken to deepen our understanding of the quantitative measures, identify facilitators and barriers, and gather information to inform technology development. Immediately after each session, the researchers and engineer or game designer (CC, RB, and HM) discussed their observational logs and field notes to compare observations, and these impressions formed the key themes and areas for refinement to improve the system. In addition, the team would debrief and discuss observations at the end of each testing day by applying an adapted constant comparison approach [51] with themes from the preceding sessions. The transcripts were sorted into emerging categorical themes related to improvements, facilitators, and barriers. This process was facilitated by 2 researchers using NVivo (NVivo Qualitative Data Analysis Software; QSR International Pty Ltd, version 11, 2016). In addition, member checking [52] was performed to confirm researchers' interpretations of the participants' statements in subsequent user testing sessions.

Results

Study Participants

Table 1 provides the demographic information of residents (13/28, 46%), staff (14/28, 50%), and family members (1/28, 4%), such as age, gender, measures of function, frailty status, and knowledge of technology. Residents had multiple physical, sensory, and cognitive impairments. All residents had vision issues, nearly half (6/13, 46%) had hearing issues, 38% (5/13) were prefrail who required moderate amounts of assistance in everyday function and PA, and 50% (6/12; data were missing for one participant) showed evidence of cognitive impairment when using an MMSE cutoff score of less than 26 [53]. The stakeholders included staff members comprised of personal support workers (8/15, 53%), managers (2/15, 13%), physiotherapist and physiotherapy assistant (2/15, 13%), life enhancement and activation therapists (2/15, 13%), and one family member who was the wife of a resident in the study (1/15, 7%). Staff were employed for at least 1 month to 4 years at their respective homes. Overall, 54% (7/13) to 77% (10/13) of residents had low to basic levels of knowledge of computers and handheld devices, respectively, whereas most staff had moderate knowledge.

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Table 1. Participant demographics and characteristics (N=28).

Characteristics	Residents (n=13)	Staff members and family (n=15)[a]
Age (years), mean (range)	83.23 (66-97)	38.38 (19-70)
Sex, n (%)		
Female	8 (61.54)	14 (93.33)
Male	5 (38.46)	1 (6.67)
Years of education, mean (SD)	14.62 (2.59)	16.13 (2.47)
Vision impairment[b], n (%)		
Yes	13 (100)	8 (53.33)
No	0 (0)	7 (46.67)
Hearing impairment[c], n (%)		
Yes	6 (46.15)	1 (6.67)
No	7 (53.85)	14 (93.33)
Mobility impairment[d], n (%)		
Yes	11 (84.62)	0 (0)
No	2 (15.38)	15 (100)
Fear of falling[e], n (%)		
Yes	3 (23.08)	N/A[f]
No	10 (76.92)	N/A
Gait aid use, n (%)		
No gait aid	2 (15.38)	N/A
Walker	6 (46.15)	N/A
Wheelchair	5 (38.46)	N/A
Knowledge of computers, n (%)		
Basic	8 (61.54)	3 (21.43)
Moderate	4 (30.77)	9 (64.29)
Advanced	1 (7.69)	2 (14.29)
Knowledge of handheld devices, n (%)		
Basic	11 (84.62)	3 (23.08)
Moderate	1 (7.69)	8 (61.54)
Advanced	1 (7.69)	2 (15.38)
Mini-Mental Status Exam score, mean (SD)	24.46 (5.30)	N/A
>24, n (%)	7 (53.85)	N/A
18-24, n (%)	4 (30.77)	N/A
<18, n (%)	2 (15.38)	N/A
Frailty in Nursing Homes Scale, mean (SD)	3.6 (2.4)	N/A
Nonfrail, n (%)	8 (61.54)	N/A
Prefrail, n (%)	5 (38.46)	N/A

[a]Missing staff data for knowledge of PCs and knowledge of handheld devices questions; denominators for residents and staff and family members were 13 and 14, respectively.

[b]Visual impairments included self-reported vision problems, the use of glasses (eg, reading glasses), cataracts, and glaucoma.

[c]Hearing impairments included self-reported hearing problems and the use of unilateral or bilateral hearing aids.

[d]Mobility impairments included hemiparesis, unsteady gait, and uneven gait due to pain.

[e]Self-reported.

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[f]N/A: not applicable.

Usability Testing

In total, 4 iterative rounds were conducted to develop the MouvMat, and a summary of the development is presented in Tables 2 and 3. One resident participant refused data collection after enrollment; therefore, the analysis included 12 residents. Overall, 25% (4/12) of LTC residents provided responses for one round of usability testing, 50% (6/12) completed 2 rounds of testing, and 25% (4/12) attended 3 rounds of testing. Data from staff and family members were analyzed together. Among this group, the majority (11/15, 73%) attended 2 rounds of testing, with 20% (3/15) attending one round and 7% (1/15) attending 3 rounds. Not all individuals participated in all rounds of testing for reasons related to doctor or dentist appointments, day trips, and availability of the residents. The areas of refinement were primarily guided by observations during participant interactions with the system. After each round of usability testing, the SUS, PACES-8, and m-TEI were collected and are reported in Figure 1 (Multimedia Appendix 2 provides scores). The data from all rounds of usability testing were summarized and categorized according to the study objectives: acceptability, usability, and PA enjoyment.

Table 2. Summary of iterative development process presented in rounds 1 and 2.

Round	Description of prototype	Primary areas for refinement
1	• Presentation: participants were presented with a low-fidelity prototype of the MouvMat, which consisted of 4 modular gaming squares. Each square was made of polyethylene terephthalate plastic with 59 RGB[a] LEDs embedded and distributed in 6 parallel rows of 7 to 11 LEDs each, with no alignment of columns. Each square contained its own pressure sensor and was wired to an Arduino. Thus, there were multiple wires connecting each square to the Arduino • Each side of the square measured approximately 28 cm (11 inches). A nonslip backing was on each square • Programming: there were no games programmed into the interface because this first stage was to identify whether this type of platform would be tolerated by the residents. The lights were manually activated by a team member to emulate game play to see how residents interacted with this gaming format • Audio: none • Pressure sensors: none • Peripheral accessory: wheel-bound participants were given a wooden stick with a circular platform at the end to use as the accessory • Image of prototype used in round 1	• Participants did not like the multiple wires (because of fall risk) • Requested to hear sounds for audio feedback • Participants found it difficult to envision a game and wanted to experience *playing a game* • The wooden stick provided to residents to emulate the peripheral device was reported by residents to be *a little heavy* and needed a larger surface area at the bottom to activate the squares
2	• Presentation: 4 acrylic (polymethyl methacrylate) squares that were all centrally connected to the Arduino. There were 6 to 10 parallel rows of 7 to 11 LEDs in each row. Each side of the square measured approximately 28 cm (11 inches). A nonslip material was on the back of each square • Programming: there was one game programmed similar to *Simon Says* programmed on the Arduino • Audio: basic audio chimes played over a mid–low-fidelity speaker when the squares were activated. There were also short music clips that would play upon the successful completion of a sequence • Pressure sensors: Velostat sheet (polymeric foil) • Peripheral accessory: wheelchair-bound participants were given a plastic stick with a circular platform on a swiveling head to use as the accessory • Image of prototype used in round 2	• Participants suggested more squares for a bigger play space to experience more gaming options • Some shoes were extending over the border of the square, so we needed larger squares to accommodate size 12 shoes • Residents wanted to see more games • The accessory's circular platform was *too heavy* and not long enough according to residents • The basic audio chimes that were added were not motivating enough • The game was not responsive enough—the squares had to be stepped on multiple times to activate • Staff identified that lifting the stack of squares would be *a bit too heavy* if they had to carry the squares from one recreation room to another room or unit • From a development perspective, the programming of the games was time consuming, and we found the single Arduino was fragile and hard to upgrade

[a]RGB: red, green, blue.

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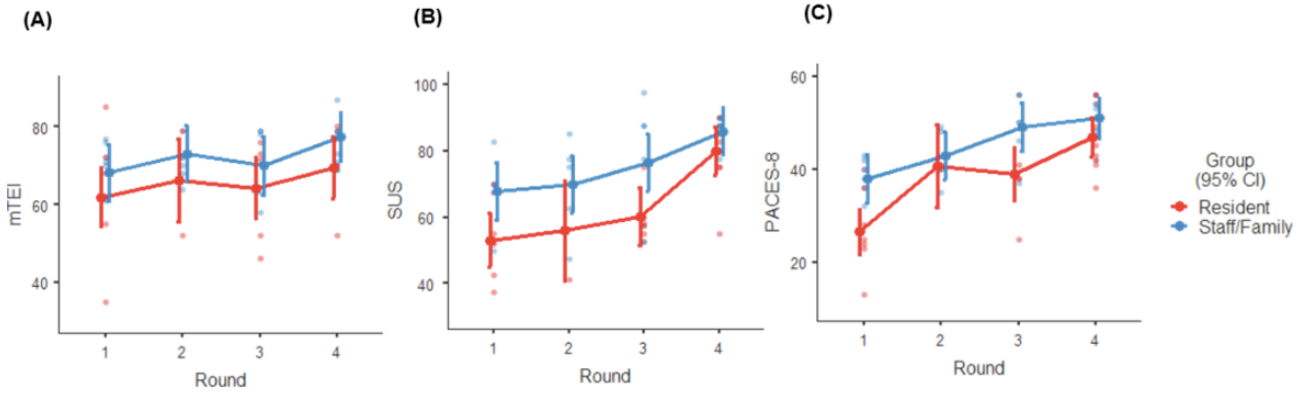
Table 3. Summary of iterative development process presented in rounds 3 and 4.

Round	Description of prototype	Primary areas for refinement
3	• Presentation: increased the number to 6 polycarbonate squares that were approximately 20% larger than the previous iteration (33 cm/13 inches side); each pad was reconfigured to have its own microcontroller that could be controlled wirelessly. The male-female connectors were replaced with magnets for quick assembly. Each square has an 8×8 matrix of RGB[a] LEDs that can be controlled individually, providing the possibility of low-level graphics. To make each square lighter and easier to carry, we used a die-cutter to create custom antistatic high-density polystyrene cushioning to replace the plywood from the first 2 prototypes • A master square is powered using a P10 connector, and the power is distributed to the other squares by the magnets • Programming: there were 4 games—Simons Says, Memory Pairs, Scrabble, and Don't Let the Music Stop. The squares work independently of each other and are connected to a Raspberry Pi server that controls the pads and provides an infrastructure for game development in high-level languages such as Python and JavaScript • Audio: improved sound quality of chimes and audio voices and music played remotely • Pressure sensors: Velostat sheet (Polymeric foil) • Peripheral accessory: a telescopic aluminum stick to adjust the length and reach; features a circular foam platform on a swiveling head to use as the accessory  • Image of prototype used in round 3	• Participants suggested that the images on each square could be sharper or higher resolution • Requested more games • Requested more squares • Requested music and improved sound quality • Residents commented that the accessory could be more comfortable to hold in their hands
4	• Presentation: the number of squares was increased to 9, each the same dimensions of iteration in round 3. A new 3D printed frame was created to accommodate the new stronger magnets that were partially embedded to prevent the separation of tiles. Each square has a 16×16 matrix of RGB LEDs to increase the resolution. A nonslip material was on the back of each square • Programming: there were 5 games programmed in Python: Simons Says, Memory Pairs, Scrabble, Don't Let the Music Stop, and Tic-Tac-Toe. New easy-to-use gaming interface that can be used on a tablet to select the game and adjust background music volume or mute it • Audio: background soundtracks with volume adjustment, audio voices, better quality speakers • Pressure sensors: Piezo sensor • Peripheral accessory: adjustable telescopic pole with foam grip and foam circular bottom to optimize comfort, lightweight, and adjustability  • Image comparing a square from round 3 (left) with a square with a higher resolution display in round 4 (right)  • Image of a high-fidelity version used in round 4	• Future development plans include but are not limited to the following: (1) adding ID readers for individual user identification and game selection; (2) replacing glued magnets with screws; (3) increasing the level of magnet embedding; (4) logging infrastructure; (5) including the possibility of playing the games on a regular computer, tablet, or cellphone over the web; (6) developing more games; (7) logging the infrastructure of performance data for automated user performance data collection; (8) adjusting the level of difficulty for each user or user group; and (9) increasing the resolution of presented graphics

[a]RGB: red, green, blue.

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Figure 1. Quantitative measures of (A) acceptability, (B) usability, and (C) physical activity enjoyment among participants across 4 rounds of testing (means and CIs). m-TEI: Modified Treatment Evaluation Inventory; PACES-8: 8-item Physical Activity Enjoyment Scale; SUS: System Usability Scale.



Exergame Acceptability

Acceptability of end users and stakeholders is important to understand, as it impacts intervention use and uptake [39]. The results of the mixed linear model analysis of m-TEI scores (Figure 1) showed that, as modifications were made based on user feedback over the 4 rounds of testing, m-TEI scores increased, indicating improved acceptability ($F_{3,21.7}$=3.92; P=.02). There was no significant effect of group ($F_{1,24.1}$=2.59; P=.12) or interaction between group and round of usability testing ($F_{3,21.7}$=0.07; P=.98).

This trend of increasing acceptability is consistent with participant responses during interactions with successive prototypes and comments during the semistructured interviews. During the initial testing session, residents and stakeholders all confirmed that they had not encountered an exergaming system or technology such as the MouvMat. On the basis of the items in the m-TEI, all respondents found the concept of the exergame—a set of interactive and configurable squares that the user engages with their feet or an accessory—to be acceptable. From round 1, the overall general reaction toward the MouvMat was scored *very positive* and scores continued to improve. Overall, based on common sense notions about regular activity, all respondents indicated on the m-TEI that the use of the MouvMat could improve PA, social activity, and cognitive stimulation. During the interviews, positive feedback from staff included:

> *I think it's a really interesting idea. It is definitely something that would engage the residents in physical activity. This is something they can have in their rooms. It can be good for residents who prefer to be alone. I think that's a really good idea.* [P16, staff]

Residents identified that the potential for PA in an upright or seated position was a strength that bolstered its acceptability. Residents were willing to use the MouvMat themselves, and staff members and family found it suitable for those who did not regularly exercise and particularly liked the use of a peripheral accessory for residents who are nonweightbearing or in wheelchairs.

Key determinants of acceptability that were identified in round 2 interviews included mitigating the potential risk of falls and ensuring that game use was intuitive rather than cognitively taxing. Falls or a loss of balance while standing or from moving square to square was the primary risk and harm mentioned by staff (5/15, 33%) and residents (4/13, 31%). To address this concern, the team highlighted the nonslip surface of the squares to participants during testing rounds and ensured that further development would address attributes that would reduce fall risk and fear of falling. A staff member said:

> *I don't feel like I'm going to slip when I'm standing on it, but I think it would be easier for residents with rollators if the squares could be made more flush to the ground and larger.* [Recreational therapist]

To respond to this suggestion, the team also developed thinner squares that were closer to the ground made of high-density polystyrene in round 3. In addition, without any programmed games in the prototype in round 1, some residents (3/13, 23%) requested to play a programmed game to fully experience the cognitive and social aspects of game play:

> *I couldn't figure out why the light went from one [square] to another or where to step first...I think playing an actual game with goals would help.* [P02, resident]

This sentiment revealed that games needed to be developed and that these future games needed features that are intuitive to users, such as a greeting message to inform the player of when the game was about to start. We responded to this resident request by programming games for subsequent rounds and integrating game design elements such as adding greeting messages and a count down with blinking lights in subsequent rounds. In the final round, we observed that participants appeared more eager to start playing the game as they were watching the countdown. The residents and stakeholders confirmed liking these intuitive game design aspects, which increased the overall acceptability of the platform.

Qualitative interview data collected in round 3 revealed features of gameplay and user experience that participants considered important to improve acceptability, including the use of sound feedback and motivating, familiar games. Participants suggested the addition of sound-based feedback to the game, indicating that they would enjoy hearing music ("Music would be great for them. They will train more if there is music" [P07, staff])

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and sounds indicating their game performance ("What if you had sounds? One [sound] that is positive, a beep or a pause or you could do the other ones. Like in other words if it's a failure or if you guess something wrong, it would go 'buzzzz'. That would be it!" [P18, resident]). Audio feedback with simple tones was introduced in round 2, and we improved the audio to become more sophisticated in subsequent rounds, which was well received based on participant interviews. By round 4, the system was playing segments of familiar songs and could support better quality sounds with higher sample rates and featured user volume control. In total, 2 residents stated that they did "not like games in general" (P01 and P22) and, in later sessions, when both experienced playing a game on the exergame platform, they both appeared motivated and excited to engage with the technology as documented through observations. For instance, the residents wanted to continue playing and expressed excitement and disappointment at the last level. During the interviews, residents suggested games they wanted the team to develop and indicated that game selection would be a determining variable about whether they would use the MouvMat in their daily routines:

> *...it depends on the types of games that it provides. Like some games could be more mentally stimulating than others.* [P22, resident]

Residents suggested classic games such as snakes and ladders, scrabble, matching or memory games, bingo, tic-tac-toe, and checkers.

Exergame Usability

The mean, SD, and range of SUS scores for each round are reported in Figure 1 and Multimedia Appendix 2. The mixed linear model predicting SUS scores showed a significant main effect of group ($F_{1,22}$=13.46; P=.001), with higher usability ratings among staff and family members. SUS scores also significantly improved across the 4 rounds of testing ($F_{3,37.4}$=14.30; P<.001). There was no interaction ($F_{3,37.4}$=0.76; P=.52). Notably, the responses by the fourth iteration of the prototype exceeded the standard cutoff score for acceptable usability [42].

This is indicative of improved usability, as the team addressed the needs identified by residents and stakeholders in previous rounds, as summarized in Tables 2 and 3. A significant number of modifications were made to the hardware design of the MouvMat to increase usability, and changes were made based on observations and interviews while participants interacted with the prototype. Some examples of modifications based on observations included increasing the size of the squares to better accommodate larger shoe sizes, so they did not activate multiple squares at once; reducing the thickness of the squares and removing the wires to embed wireless connectivity to reduce fall risk and make it easier for residents with gait aids to navigate around the MouvMat; and changing the pitch and size of the LED lights to increase the definition of images while reducing glare, as some participants asked what shape or letter was on square. Observations of staff assembling and disassembling the MouvMat indicated some confusion matching the male-to-female physical connectors, and when we asked about that aspect, it was confirmed in the interview that staff preferred lighter squares with an automatic mechanism:

> *If I have to carry a bunch of these squares, it'll be heavy to bring them up and down from floor to floor...I would like to just throw on the ground and have it assemble by itself without me thinking too much.* [P07, staff]

In response to this staff need, we redesigned the frame and replaced the male-to-female physical connectors with strong magnets that would self-assemble the MouvMat to make it as easy as possible for staff. In addition, we replaced the internal components to reduce the weight of the tiles. By observing how residents were holding the peripheral device and inquiring during the interview, it became clear that we needed to make changes to the peripheral accessory to make it lighter and more comfortable for the residents to hold and use. During the testing period, we designed and tested games that were based on residents' interests as reported during semistructured interviews (refer to Multimedia Appendix 1 for game descriptions). To respond to stakeholder feedback, the games were programmed to be customizable at the speed and difficulty level to accommodate the user.

Exergame Enjoyment

Figure 1 and Multimedia Appendix 2 outline the mean, SD, and ranges of PACES-8 scores from the 4 rounds. The mixed linear model predicting PA enjoyment scores from the PACES-8 revealed a significant main effect of group ($F_{1,32.7}$=11.00; P=.002), with higher enjoyment ratings among staff and family members compared with residents. There was a significant increase in enjoyment scores for the MouvMat across the 4 usability sessions, as the games were modified ($F_{3,43.4}$=19.47; P<.001). There was no interaction between the group and the testing session ($F_{3,43.4}$=1.40; P=.25).

Importantly, semistructured interviews indicated that many participants thought that the MouvMat would be enjoyable to use, which would increase residents' PA levels:

> *This encourages physical activity and I think that is useful. It was mentally stimulating and physically engaging, I quite enjoyed it.* [P01, resident]

All participants, including residents, agreed that increasing PA and cognitive stimulation would be beneficial. Specific characteristics of the system that were identified as important to enjoyment included the potential to individualize needs for independent or group use, a combination of cognitive stimulation with PA, increasing social interaction with others, and novelty of engaging in a new activity. Several staff participants shared that they felt the exergaming system could improve the autonomy of residents' PA routines because it allows them the opportunity to engage in independent physical exercise:

> *Rather than having the physiotherapist go around to every single resident's room, I think this is another way for the [residents] to be able to do [physical activity] on their own...either in their room or activity area.* [P20, staff]

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In line with the research team's goals, participants also spoke about how they felt that the system was an effective way to combine both cognitive and physical stimulation:

> *Yeah, I liked that it provided the cognitive and physical activity together. I like the idea because you are using both your mind and your body at the same time, so there should be coordination.* [P24, resident]

In addition, the opportunity to increase social interactions and engagement among residents in LTC during PA was perceived as a benefit of the MouvMat. Staff members shared during interviews that they believed MouvMat would increase residents' current social circles by providing them with an opportunity to engage with other residents who they would not normally interact with, for example, residents could use the mat together or residents could watch others compete during gameplay. As explained by one staff member:

> *I think bringing two people together to play a game against each other or bring a group together to watch two people play against each other will build relationships and create social situations, interactions...they can cheer each other on.* [P21, staff]

Respondents liked that it provided a new opportunity for them to engage in a different task with others:

> *Yeah, I like movement and I like something new!* [P03, resident]

> *other than having it in their rooms, having [the MouvMat] in a public activity area could engage residents in games with other residents that they don't usually talk to.* [P21, staff]

Facilitators and Barriers to MouvMat Implementation

Through semistructured interviews with staff participants, we identified the facilitators and barriers to MouvMat implementation in the LTC setting. The 3 most frequently identified facilitators of new technology adoption in their LTC homes were the importance of empirical evidence to support the benefit of the technology to residents, ease of use, and versatility of the technology. Staff decision makers indicated that they take into account whether new interventions or technologies have any research or proven benefits for LTC residents. Staff also emphasized the need for the exergame design to be lightweight, compact, and quick to set up because of the heavy workloads. The life enhancement and activation therapists service the entire home, which requires them to travel between units and the various recreation rooms. In addition, the lack of physical space was identified as an issue, so new interventions need to be adaptable to fit different-sized common areas and activity rooms. Furthermore, because of the lack of space, exergames that are versatile and could provide a variety of activities that are customizable to the residents' abilities are highly preferred. Technologies that considered the contextual realities of the LTC home that most residents could realistically use were more likely to be purchased.

The primary barrier to the acquisition of new technology in LTC home adoption is cost. All the staff stakeholders identified cost as a barrier and explained how available funds were influenced by different variables, including home fundraising efforts, the annual funding envelope to support activities, and whether the payment model for the technology was an outright cost or a subscription-based service requiring ongoing payments. The second barrier was a fear of harm or falls mentioned by 2 staff members; however, both respondents agreed that the accessory for wheelchair-bound residents would be an effective way to still have residents engage in upper limb activity while reducing fall risk.

Discussion

Principal Findings

This paper presents the development of a novel exergaming intervention co-designed with LTC residents with varying cognitive and physical abilities as well as the primary facilitators and barriers to the implementation of this exergaming platform in the LTC home setting. A robust UCD approach was used, which included validated measures and inputs from key stakeholders, such as LTC residents, their family members, and staff members. There were upward trends in the acceptability, usability, and enjoyment scores of MouvMat over time, indicating that the identified themes were appropriately addressed by the team. Key features that were identified by participants as important to increase exergame acceptability included the possibility of playing with it in either a seated or standing position, minimizing fall risk, intuitive gameplay requiring minimal instruction, auditory performance feedback, and familiar games. Improvements in usability across successive prototypes focused on the size, thickness, and weight of the squares, ease and comfort of using the peripheral accessory, and improving visual clarity of the display. Contributors to the enjoyment of the exergame included the opportunity for social interaction with other residents as well as the sense of novelty that the exergame provided. In addition, staff and stakeholders were drawn to MouvMat's ability to increase residents' autonomous PA. These findings are consistent with the current literature on habitual PA, which suggests that reducing health risk factors and maintaining functional abilities are among the most common self-reported intrinsic motivators for engaging in exercise among OAs [54-56].

OAs with cognitive impairment, as indicated by the MMSE score (Table 1), can also be included in exergame activities that use simple and familiar games. By actively engaging OAs residing in LTC homes and other stakeholders in the design process, researchers and developers can design more suitable exergaming interventions that avoid the limitations of existing commercially available exergames [19]. Our observations and interviews revealed that residents enjoyed engaging with the prototypes, appreciated the opportunity to increase their PA, and appreciated the novelty of something different from their usual routine in LTC. Besides the residents, staff were excited to see the development between the rounds and were very interested in the creation of the MouvMat. Our usability study demonstrates that an exergame can be co-designed to meet the diverse requirements (ie, hardware design features and motivation) and constraints (ie, residents' physical and cognitive

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impairments) of end users. LTC residents are a historically challenging group to conduct research with [57-59], especially those with cognitive impairment [60-62], and as such have often been excluded from research [63]. An in-depth understanding of the complex physical, cognitive, and medical complexities of this population is imperative because LTC residents often experience symptoms, including fatigue and hearing or visual impairments, which can severely impact all aspects of the research, especially recruitment, retention, and data collection [58]. When collaborating with this population, it was important that all members of the team were knowledgeable about OAs in LTC; for instance, the 2 authors (CC and RB) are clinicians specializing in geriatrics, and the design team (led by HM) had previously created technologies for OAs. Special considerations when working with this population [62,64] included assessing assent, using effective communication strategies to fill out the validated tools, and conducting interviews. Researchers who have a strong understanding of the illness trajectory and who have experience with OAs can use appropriate strategies and approaches to ensure ethical and accurate data collection. Furthermore, additional considerations that may be unique to our study were that the setting was distraction free and private for testing and interviews, eliminating all safety risks during testing, such as checking for nonslip shoes and confirming that no recent medications were taken, as well as adjusting for the clinical realities of the LTC setting. Consistent with other studies [62], we also experienced user testing sessions being postponed or canceled if the resident was ill or had a medical appointment and scheduled for other activities, and residents often felt too lethargic to engage in PA after lunch; therefore, patience and open and empathetic attitudes from all team members were essential.

The development and adoption of innovative exergaming technologies for clinical settings, such as LTC, is inherently complex and is a context in which researchers must work within existing financial constraints. The main barriers to the implementation found in this study were the operational cost, followed by the risk of harm. The barriers to uptake in this study are corroborated by existing research in gerotechnology [65-67]. The most common facilitators reported were the intended and perceived benefits of MouvMat use, ease of use, and versatility of the technology, so that it can be used by a diverse group. MouvMat's design minimizes fall risk and can be used from standing and seated positions and addresses accessibility issues faced by OAs with physical disabilities. Identifying facilitators and barriers is a foundational building block for generating a viable knowledge translation plan. Moving forward, we anticipate adopting an integrated knowledge translation approach [68,69], which is a continuation of the ethos of the UCD approach used in this study.

This project aims to create new exergaming technologies that are of value to the LTC sector and, in doing so, generate new scientific directions for the development and assessment of new exergaming platforms that can promote physical, cognitive, and social activity for LTC residents. In this context, it is important to develop appropriate exergaming interventions that meet the needs and interests of residents. Future research directions include conducting a pilot multisite randomized controlled trial to evaluate whether MouvMat can improve physical, cognitive, and psychosocial outcomes in LTC residents. Additional work with stakeholders to elucidate further facilitators and barriers to exergaming technology acquisition into LTC homes using an integrated knowledge translation approach would also be valuable. This research project has the potential to radically broaden our conceptualization of how to co-design exergaming technologies for OAs living in LTC homes.

Strengths and Limitations

This study had several strengths. First, a user-centered approach was used and included residents with various levels of functional ability and cognitive function and other stakeholders, including staff members with different positions (eg, physiotherapist, life enhancement, and personal support worker) and family members. Second, we collected interview data and validated quantitative scales to measure participant acceptability, usability, and enjoyment to generate a comprehensive understanding of refinement needs. Third, the trustworthiness of the data was enhanced by member checking and triangulation across data sources (eg, observations, think-aloud responses, and interviews). Fourth, an independent observer was present on each testing day, which provided another perspective. Finally, an interdisciplinary team that included health care, psychologists, game developers, and engineers provided different perspectives.

The findings of this study should be interpreted with caution because of the following limitations. First, the study sample included a relatively small number of participants and included 2 mid- to large-sized nursing homes in Canada, which may impact the generalizability of the results to other contexts. Although a concerted effort was put forth by the team to get residents and stakeholders to complete all 4 rounds of usability testing, this was not feasible based on scheduling conflicts with appointments and illness or injury unrelated to the study. We also noted that difficulty retaining participants is a common challenge in research on OAs in LTC [62]. Nonetheless, most participants completed at least two rounds of user testing and were able to provide feedback, as the prototype became more sophisticated over time. It should also be noted that the analysis of the average MMSE scores of participants who completed the rounds indicated that selective attrition of participants with poorer cognitive function and frailty was not an issue; in particular, MMSE scores were lowest in participants who completed 3 rounds of testing. Second, the interviewer for some of the interviews was a member of the research team, which may have prevented participants from sharing negative opinions that criticized the exergame. We believe that the use of a question guide with open-ended questions and allowing the participants to speak freely, as well as triangulation [50,70] of the data, contributed to the validity of the results.

Conclusions

Our study demonstrated that an exergaming platform could be cocreated with LTC home residents with multiple cognitive and physical impairments, who are a challenging group to engage in research. A user-centered, iterative design process was applied to successfully refine an exergaming platform to increase its acceptability, usability, and enjoyment for LTC residents.

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Facilitators and barriers to the future implementation of the MouvMat into LTC were identified, and this knowledge will contribute to an integrated knowledge translation plan. Cost was the major barrier to the acquisition of new technology; however, despite this barrier, residents and stakeholders were positive overall about its potential to improve OAs' physical health and social engagement. The next research steps include determining the effectiveness of the MouvMat in a future multisite randomized controlled trial and developing analytics of game performance to indicate improvements or declines in physical and cognitive function. This research project focuses on safe and ethical cocreation of exergaming interventions with residents in LTC to address the exclusionary technology development process that traditionally overlooks LTC residents.

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Descriptions and instructions of the games that were tested during the usability study.
[DOCX File , 14 KB - games_v9i1e22370_app1.docx]

Multimedia Appendix 2
Exergame usability, enjoyment and treatment evaluation inventory scores stratified by participant type and round of testing.
[DOCX File , 15 KB - games_v9i1e22370_app2.docx]

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Abbreviations

AGE-WELL NCE: Aging Gracefully Across Environments Using Technology to Support Wellness, Engagement and Long Life Networks of Centers Excellence
FRAIL-NH: Frailty in Nursing Homes Scale
LTC: long-term care
MMSE: Mini-Mental Status Examination
m-TEI: Modified Treatment Evaluation Inventory
OA: older adult
PA: physical activity
PACES-8: 8-item Physical Activity Enjoyment Scale
SDM: substitute decision maker
SUS: System Usability Scale
SWOT: strengths, weaknesses, opportunities, and threats
UCD: user-centered design

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Original Paper

A Virtual Reality Game to Change Sun Protection Behavior and Prevent Cancer: User-Centered Design Approach

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Abstract

Background: Public health sun safety campaigns introduced during the 1980s have successfully reduced skin cancer rates in Australia. Despite this success, high rates of sunburn continue to be reported by youth and young adults. As such, new strategies to reinforce sun protection approaches in this demographic are needed.

Objective: This study aims to develop a virtual reality (VR) game containing preventive skin cancer messaging and to assess the safety and satisfaction of the design based on end user feedback.

Methods: Using a two-phase design approach, we created a prototype VR game that immersed the player inside the human body while being confronted with growing cancer cells. The first design phase involved defining the problem, identifying stakeholders, choosing the technology platform, brainstorming, and designing esthetic elements. In the second design phase, we tested the prototype VR experience with stakeholders and end users in focus groups and interviews, with feedback incorporated into refining and improving the design.

Results: The focus groups and interviews were conducted with 18 participants. Qualitative feedback indicated high levels of satisfaction, with all participants reporting the VR game as engaging. A total of 11% (2/8) of participants reported a side effect of feeling nauseous during the experience. The end user feedback identified game improvements, suggesting an extended multistage experience with visual transitions to other environments and interactions involving cancer causation. The implementation of the VR game identified challenges in sharing VR equipment and hygiene issues.

Conclusions: This study presents key findings highlighting the design and implementation approaches for a VR health intervention primarily aimed at improving sun protection behaviors. This design approach can be applied to other health prevention programs in the future.

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KEYWORDS

virtual reality; gamification; primary prevention; health promotion; skin cancer; mobile phone

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Introduction

Background

Australia has one of the highest rates of skin cancer in the world, with sunlight or ultraviolet radiation being the main risk factor for skin cancer [1]. Over the past three decades, Australia has successfully implemented world-class skin cancer prevention campaigns, such as Slip! Slop! Slap! and the SunSmart program using standard media channels, including posters, brochures, television, radio, and newspaper advertising [2,3]. The SunSmart program has led education, policy, and environmental intervention in schools, workplaces, and public settings, and these programs have raised public awareness and improved preventive behaviors among Australians, leading to a reduction in melanoma incidence in younger generations [4]. Despite this success, high rates of sunburn continue to be reported by young adults, with people aged between 18 and 34 years being 4 times more likely to report having a sunburn in the last 12 months than those aged over 65 years [5].

Although the reasons for youth sunburn rates are complex and multifactorial, one potential contributor is the communication platforms used to deliver sun safety messaging to this age group. Challenges include the limited reach of traditional media channels (television and print), which are not regularly consumed by modern youth, whereas digital platforms (social media) are highly competitive spaces for user attention. As such, developing innovative and appealing ways to reach people with health messages is a critical step in improving skin cancer prevention strategies.

An emerging approach that has been effective in influencing behavior change in other health-related campaigns is the combination of virtual reality (VR) and gamification. Gamification is “the use of game mechanics and experience design to digitally engage and motivate people to achieve their goals” [6] and thus may be used to encourage people to engage in healthy behavior. Examples of VR interventions to address health-related issues include pain distraction; treatment of psychiatric conditions, such as anxiety, phobias, eating disorders, and addiction; and assistance with physical rehabilitation [7-9]. VR has also been assessed for modifying health behaviors, such as smoking, diet, physical exercise, and compliance to prescribed treatment regimens [10-13]. Work in the cancer prevention setting has shown VR to enhance awareness of how to check for prostate cancer symptoms in men [14].

With regard to the user experience, a systematic review of randomized controlled trials using VR technology found that interventions were generally effective and well tolerated by users [13]. In addition, VR experiences have also been shown to improve recall compared with more traditional 2-dimensional video platforms watched on either desktop computers or tablets [15,16], and participants using VR were found to explore more of the environment than those provided with a desktop display [16].

However, although there is evidence to support the deployment of VR technology in health promotion programs, designing health interventions is challenging, and poor design choices can lead to interventions failing to meet their objectives [17]. One approach to overcome these hurdles is a user-centered design strategy. Here, content is developed using a multistage problem-solving process to assess how end users are likely to use a product and actively requires end user participation during the design process [18]. By involving end users and other stakeholders (such as individuals paying for the product, industry, and health authorities and government officials), uptake and use are increased and this ensures consistent messaging across all channels [19]. User-centered design can assist health interventions and programs that contribute to the development of more user-friendly, meaningful interventions for improving health outcomes.

Objectives

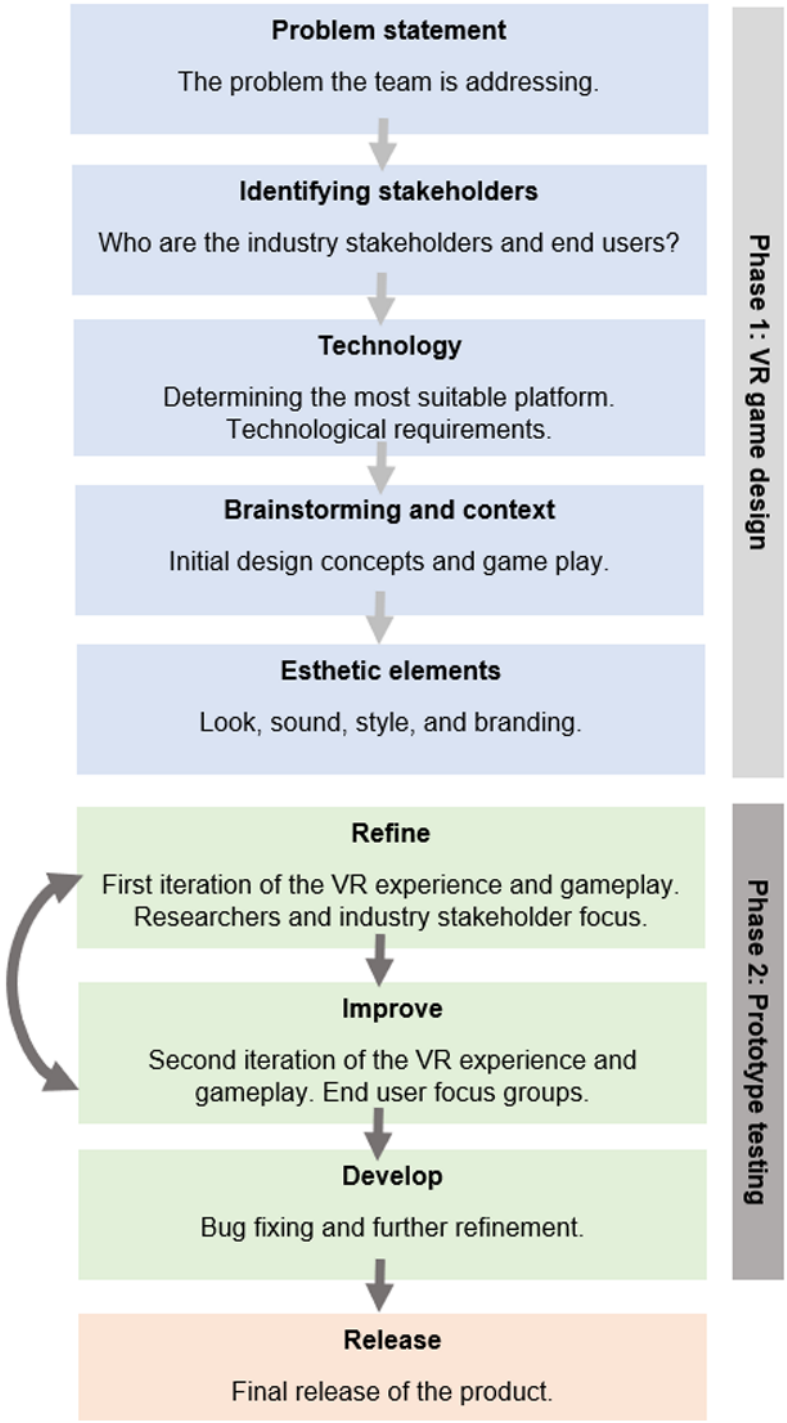
This study aims to create a VR game that provides skin cancer preventive messaging. This study describes the design process, development pipeline, and implementation experiences.

Methods

The overall process of developing the VR game included *phase 1: game design*, which involved defining the problem, identifying stakeholders, choosing the technology platform, brainstorming and context, initial development meetings, and designing esthetic elements, and *phase 2: prototype testing*, which involved pilot testing the VR experience with stakeholders and then end users in focus groups and interviews, with feedback incorporated into refining, improving, and further developing the VR experience (Figure 1).

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Figure 1. Flow chart of the design and development process. VR: virtual reality.



Phase 1: VR Game Design

Problem Statement

The team was addressing skin cancer prevention challenges in Australia. Despite previous campaigns, Australians continue to report high rates of sunburn, and people are increasingly turning away from traditional media consumption such as television and print; hence, novel approaches are required to reach this audience.

Development Team and Stakeholders

The development team comprised a multidisciplinary group including cancer researchers, software developers, science communicators, government health officers, and end users. Cancer researchers had expertise in cancer biology, clinical trial design, development and implementation, science communication, and testing of health technologies. The software developers had professional roles in the design studio *Real Serious Games*. The government health officers were

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experienced policy officers at the Preventative Health Branch. We specifically targeted end users aged 18 to 35 years who reported higher rates of sunburn; however, the game was designed to be suitable for all ages. These stakeholders contributed to the iterative design process and provided feedback on which aspects of the gamification development they liked and disliked.

Technology

During our first development team meetings, we discussed the challenges that arose when communicating cancer-themed information. A common difficulty encountered by stakeholders was the ability of target audiences to visualize and relate to the disease because of the often internal and microscopic scale of the disease. As such, the benefits of using VR technology as a communication platform were discussed.

One benefit of VR over other communication platforms is that VR allows users to be immersed in a simulated environment where they can interact with their surroundings using a headset and hand controllers. This was particularly desirable from the development teams' perspective, allowing participants to be taken into the human body to visually see how cancer occurs at a macroscopic, first-person point of view. In addition, VR has been shown to be more effective for memory recall and behavior change than digital desktop delivery [16] and can be combined with gaming elements to provide an entertaining communication channel relevant to a youth audience.

For the reasons mentioned earlier and the fact that VR as a health promotion tool has been limited, we chose to use VR technology to engage users with health information. We specifically chose the Oculus Quest platform (Facebook Technologies LLC) to deliver the VR experience because of its versatility in field delivery (ie, a stand-alone unit that does not require connection to high-end computing hardware or room motion sensors to detect movement). Unity software, a cross-platform game engine, was used to develop the game (Unity Software Inc).

Brainstorming and Context and Esthetic Elements

During the brainstorming phase, there were discussions to incorporate multiple levels and scenarios with the VR game such as interactions between the skin and sunlight, cancer cells transporting through a blood vessel, and a metastatic lung site. However, health interventions often have budgetary restraints and confining the prototype game to one level, allowed for a focused approach while still remaining within the budget. This also enabled us to develop a minimum viable product to assess whether VR was a suitable platform for our target audience while remaining within the budget. Taking the abovementioned points into consideration, the development team decided that the best approach was to develop a first-person shooter game based inside the body, depicting cancer growth and the challenges encountered with late-stage therapy. The narrative journey was also built around minimizing production costs by reducing the need to create VR visual resources; instead, a black scene with voice-over could transition the user into the experience. However, esthetic elements were an important factor in the design to ensure that the user experienced a sensation of being transported inside the human body. Considerable resources were provided to ensure that the VR visual elements were anatomically correct and had an authentic look and style.

The VR experience we created begins with audio describing how a skin cancer has invaded your body (Multimedia Appendix 1), and the user is then transported into the lungs of a human body where a dark pigmented melanoma begins to grow. A shooter game play mechanism is used to fight the cancer using several treatments, including chemotherapy, targeted therapy, and immunotherapy (Multimedia Appendix 2). The hand controllers are used to target and destroy the cancer cells, whereas a proliferation algorithm determines how quickly the cells divide and replicate. As the game proceeds, the cancer cells become resistant, requiring the player to progressively escalate through the different treatments to *defeat* the growing cancer. This was purposefully designed to demonstrate the difficulties of treating late-stage cancer and to reinforce the importance of early detection and adoption of preventative health strategies. The game ends with a prevention message conveyed by the text *not everyone wins*, followed by *prevention is the best cure* and *protect your skin everyday*. The subtle health messaging accompanying the game is designed to provide an entertaining experience while learning more about skin cancer. In summary, the VR game focuses on the difficulties of treating metastatic skin cancer and illustrates to the user how simple prevention is and why it is important.

To embed behavior change–relevant cues, we adopted the Appeal, Belonging, Commitment (ABC) framework into our design process [20]. The integrated ABC framework combines elements of the health belief model, social cognitive theory, and transtheoretical model [21] and has previously been used successfully in the context of an interactive mobile phone game teaching antiviolence norms to young men [22]. The ABC framework can be used to assume that the user's intention to perform sun protection will be influenced by the perceived value to the user (*Appeal).* It includes *Belonging* (socially based) about whether key people approve or disapprove of sun protection and motivation to behave in a way that gains their approval. Finally, it incorporates *Commitment* (stage of change), which needs to occur to ensure habitual behavior. This includes the belief that one has and can exercise a perceived likelihood of control over using sun protective behaviors. The VR game created a unique, compelling user experience designed to resonate and appeal to the user (Appeal). The game play encourages people's intrinsic need for competition and is designed to build discussion among social groups about the experience and continue to shape social norms (Belonging). The messaging at the end of the game is designed to empower the participant to take responsibility for their sun protection behaviors and motivate improved sun protection habits in the future (Commitment).

Phase 2: Prototype Testing

Refining With Stakeholders

In the first step, we tested the game play mechanisms and transition steps among a panel of industry stakeholders, including educators, science communicators, and government personnel (n=12). Each individual was asked to participate in

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a 1- to 3-minute VR experience, which included the chemotherapy treatment level. Focus groups were then undertaken on a range of topics, including enjoyment, esthetics, usability and game play design, safety, and future refinements. Notes were taken during the focus group feedback sessions by the moderator and findings reported back to the design team. No formal qualitative analyses were conducted.

Feedback from stakeholders emphasized safety aspects, and the VR game was designed as a sitting experience with visual elements designed in central fields of view to reduce head movement.

Improving With End Users

The focus groups and interviews were conducted with end users, all participants provided written informed consent, and the study was approved by the Queensland University of Technology Human Research Ethics Committee (Approval number: 1900001157). Participants were recruited via university emails and the social media platform Facebook during September (spring) in Australia.

The end users were asked to participate in one 60-minute focus group or interview, which included testing the 3- to 5-minute VR experience and providing feedback (Multimedia Appendix 3). The audio-recorded focus groups or interviews discussed a range of topics, including satisfaction with the experience, barriers to understanding the information, usability and game play design, esthetics, deployment opportunities, and safety during the experience. Thematic analysis was undertaken by one researcher (CH) following an iterative process of familiarizing oneself with data, generating initial codes, defining and naming themes, reviewing themes, and searching for themes.

Before the focus group, participants completed a web-based demographic survey and a follow-up survey 7 days after the VR experience. The post-VR survey asked if they experienced any of the following negative symptoms after use of the VR experience, including nausea or motion sickness; dizziness, disorientation, or impaired balance; altered or blurred vision or other visual abnormalities; eye strain or eye or muscle twitching; or headache. Participants were also given the opportunity to list any other symptoms experienced and were asked to provide additional details about their symptoms in an open-ended question.

Information on participants' skin color, skin cancer history, and sun protection habits were collected. The sun protection habits index was used, which queries the frequency of 7 sun protective habits that are used when outdoors using a 4-point Likert scale (1=never or rarely, 2=sometimes, 3=usually, and 4=always) [23,24]. The overall sun protection index score is derived from questions including wearing a shirt with long sleeves, wearing a hat, wearing sunglasses, wearing sunscreen with a sun protection factor (SPF) of 15 or more on the face, wearing sunscreen with a SPF of 15 or more on other parts of the body, staying in the shade, and limiting time in the sun during midday hours.

Results

End User Focus Group Characteristics

In total, 18 participants completed the focus groups. Overall, 7 focus groups were conducted, ranging from 1-4 participants per group. Participants were mainly university educated (13/18, 72%), 67% (12/18) were female, and 61% (11/18) had never experienced VR before (Table 1). The participants' ages ranged between 18 and 74 years, and more than half of the participants had sun-sensitive characteristics, such as fair skin that would burn moderately or severely after summer sun exposure (Table 1). Overall, 2 out of 18 (11%) participants had previously been diagnosed with skin cancer (both basal cell carcinoma). Participants completing the study used sun protection behaviors when outdoors sometimes to usually, with an average sun protection habits index score of 2.48 (SD 0.49; 1=never or rarely, 2=*sometimes*, 3=*usually*, and 4=always; Table 2. Female participants tended to report more frequent use of sunglasses and sunscreen on their face, whereas men reported the use of long sleeve shirts and limiting time outdoors during midday hours (Table 2). We observed a trend for increased sun protection behaviors among participants aged ≥36 years compared with younger participants aged 18 to 35 years, although this was not significant (two-tailed *t* test *P*=.08; Table 2).

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Table 1. End user focus group characteristics.

Characteristic	Baseline value (N=18)
Age (years), range	18-74
Gender, n (%)	
Female	12 (67)
Male	6 (33)
Skin color, n (%)	
Very fair or fair	10 (56)
Medium	6 (33)
Olive or brown	2 (11)
Education, n (%)	
High school or leavers certificate	3 (17)
Trade, technical certificate, or diploma	2 (11)
University degree	13 (72)
Skin burn in strong summer sun for 30 minutes without protection, n (%)	
My skin would not burn at all	1 (6)
My skin would burn lightly	6 (33)
My skin would burn moderately	9 (50)
My skin would burn severely	2 (11)
Skin tan in strong sun without protection, n (%)	
My skin would not tan	2 (11)
My skin would tan lightly	2 (11)
My skin would tan moderately	11 (61)
My skin would tan deeply	3 (17)
Previously diagnosed with skin cancer, n (%)	
Yes	2 (11)
No	15 (83)
Unsure	1 (6)
Previously experienced virtual reality, n (%)	
Yes	6 (33)
No	11 (61)
Unsure	1 (6)

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Table 2. End user focus group sun protection habits (N=18).

Sun protection habit	All participants, mean (SD)	Female (n=12), mean (SD)	Male (n=6), mean (SD)	Age <35 years (n=9), mean (SD)	Age >36 years (n=9), mean (SD)
Overall SPH index[a]	2.48 (0.49)	2.55 (0.46)	2.36 (0.56)	2.29 (0.44)	2.68 (0.47)
Wear a shirt with long sleeves	2.39 (0.78)	2.33 (0.78)	2.50 (0.84)	2.33 (0.87)	2.44 (0.73)
Wear sunglasses	2.89 (1.02)	3.08 (0.90)	2.50 (1.23)	2.78 (1.09)	3.00 (1.00)
Stay in the shade	2.72 (0.46)	2.75 (0.45)	2.67 (0.52)	2.67 (0.50)	2.78 (0.44)
Limit your time in the sun during midday hours	2.83 (0.92)	2.75 (0.87)	3.00 (1.10)	2.56 (0.88)	3.11 (0.93)
Wear a hat	2.00 (1.09)	2.08 (1.08)	1.83 (1.17)	1.78 (0.97)	2.22 (1.20)
Wear sunscreen with an SPF[b] of 15 or more on your face	2.50 (0.99)	2.67 (0.89)	2.17 (1.17)	2.11 (0.78)	2.89 (1.05)
Wear sunscreen with an SPF[b] of 15 or more on other parts of your body	2.06 (0.94)	2.17 (0.84)	1.83 (1.17)	1.78 (0.83)	2.33 (1.00)

[a]SPH Index: The overall sun protection habits index score is derived from items including wear a shirt with long sleeves, wear sunglasses, stay in the shade, limit your time in the sun during midday hours, wear a hat, wear sunscreen with an SPF of 15 or more on your face, wear sunscreen with an SPF of 15 or more on other parts of your body.

[b]SPF: sun protection factor.

End User Focus Group Side Effects

During the VR experience, the participants remained seated and were not required to walk around. This prevented participants from losing balance or slipping, thereby reducing trip hazards. Overall, 2 out of 18 (11%) participants reported that they felt nausea during the VR experience; this was extended for 1 of those participants, who reported nausea and headache 24 hours after the VR experience. Nausea may become more apparent if the headset is fitted incorrectly or has a poor focus. It is important to fit the headset correctly, even for short experiences. Some participants reported that the headset felt heavy, was slightly out of focus, or was too loose. In addition, 1 participant identified that they had a sore neck if they looked up often and that they would prefer not to have too much content in their peripheral vision.

End User Focus Group Qualitative Analysis

Qualitative analysis of participants' discussions resulted in the identification of several themes, which are described below and detailed in Table 3.

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Table 3. End user focus group qualitative analysis themes and descriptions.

Theme	Description	Participant quotes
Engaging and appealing to play	The VR[a] experience was described as "fun," "enjoyable," "hands-on," "enlightening," "insightful," "impactful," "immersive," "rewarding," "informative," "cool," "illustrative," "informative," "serious," "awesome," "powerful," "unique," and "awe inspiring." Participants prefer VR over other presentation formats, such as videos or brochures. Participants identified being bored or distracted watching videos, and there was a better connection to the environment in the 3-dimensional immersion.	• "To actually look at the cancer at a cellular level...it was awesome." (Male, 36 years) • "Different way I guess to learn about cancer, but to see cancer, how it grows, and how therapy can be ineffective." (Female, 30 years) • "The skin cancer message got across so much better when you felt like you were in it [the human body]." (Female, 26 years) • "It's [VR] much more powerful than a brochure." (Female, 64 years)
Competition and challenge to beat cancer	Participants observed how the cancer could grow and change.	• "...makes you think how quickly they [cancer] grow." (Female, 27 years) • "It's a good indication of how quickly something like that [cancer] can progress." (Female, 30 years) • "I think it was fun, but I think you also did see the point in there about the cells dividing and how much of a battle it [cancer] really is." (Male, 47 years)
Simplifying complex information	The information is displayed in a simple and easily understandable way.	• "I loved how it actually broke down what was a very complex problem, into a very simple idea." (Male, 36 years)
Promotes discussion	Participants would talk to others about the VR experience. It was identified as a good education tool for children.	• "It would be something that kids would run home and talk to their parents about." (Female, 44 years) • "Can someone take a photo I want to put it on Twitter." (Female, 30 years)
Stronger connection to cancer prevention	Participants would like more context-relevant visual cues on prevention to show the journey of a cancer cell from where it originates. Suggestions include starting the game outside the body with an individual being sunburnt, showing the response of skin cells to sunlight and how this leads to skin cancer.	• "You do lose a little bit of the skin cancer – sun protection message because you are so excited about immunotherapy and the different cancer therapies." (Female, 46 years) • "I don't draw the link then to put a hat on... so there needs to that better link." (Female, 40 years) • "The game would be better if it was more of a journey. ...You didn't really know it was about skin cancer until the end." (Male, 47 years)

[a]VR: virtual reality.

Engaging and Appealing to Play

Participants found the game was engaging, simplified complex information, and provided a unique gamification experience. All participants (n=18) reported that they liked the VR experience and that it was appealing and engaging. Of the 18 participants, 16 said that they would play the game again. Participants were asked whether they would prefer the VR experience over the same content provided in a video format. Most participants preferred the VR format because they felt like they were in the body, and it was more hands-on and engaging.

Competition and Challenge to Beat Cancer

The proliferation of cancer cells was created using an algorithm that can be increased or decreased to change the speed of growth. Most participants were not too overwhelmed when the cancer was growing during the different treatments. The cancer cells were designed to continually grow out of control, and some participants identified that it felt stressful and unachievable to fight against. One participant commented that this is an accurate representation of how it may feel to fight against cancer in real life. Most participants felt like they were winning, especially toward the end of the game during the immunotherapy stage.

A participant suggested that a scoreboard may help show how well they were progressing or playing. However, there was no consensus regarding having a scoreboard, as some participants liked the idea, whereas others said it may take away from the seriousness of the issue at hand and would not add value. One participant said that it would be difficult to have a metric or score that would be a suitable indication of a real-life scenario. The experience was seen primarily as educational, rather than just a game to win. If a scoreboard was to be included, participants discussed preferences for incorporating a bar showing the effectiveness of treatments, which would use a word scale such as high or low rather than a numbered scoreboard. Including a message on the scoreboard at the end of the game showing the cancer is in remission was also suggested and supported by participants.

Simplifying Complex Information

Most participants identified that the experience depicted complex information in a simple and easy-to-understand way.

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Promote Discussion

All participants said they would share the VR experience with their friends or family.

Stronger Connection to Cancer Prevention

Participants identified that the link between skin cancer prevention and fighting the cancer cells was not immediately clear until the end of the experience when this was depicted via audio and text on the screen stating *prevention is the best cure* and *protect your skin everyday*. A few participants suggested that the main message of the VR experience was learning about the different types of cancer treatment, rather than what causes cancer and how to prevent cancer.

Most participants would like to have a debrief after the VR experience to learn more information, and some participants identified that the focus group discussion enhanced their learning from the game. During the focus group, participants were provided with a debriefing A3 poster, which explained the different treatments used in the game (Multimedia Appendix 4). If the VR experience was deployed during an event in a public setting, providing debriefing information using a brochure, poster, or quick response code linking to a website was suggested. If users were to download the game and play at home on their headsets, it was suggested that the debriefing material could be delivered via email or a website.

Participants suggested that the prevention message could be stronger and depicted visually (rather than text alone), for example, showing an individual in the sun, zooming in to a mole on the human body, and then showing how a mole can transition to cancer and spread to other organs. Participants supported the concept of a multistage game transiting through levels, which highlight the journey of a cancer cell. The current VR experience was 3 to 5 minutes, and most participants would prefer a longer VR experience (on average approximately 10 minutes). Some participants qualified they would only play longer if the experience involved multiple levels or stages and continued to be interactive (ie, not just listening to content). All participants were interested in further content depicting the interactions between sunlight and the skin. Most participants were interested in viewing the journey of the cancer cell, as it was transported through the body, and some participants were interested in other treatment types such as radiotherapy. Extending the game into a multistage game could be part of a future project; however, balancing the health impact and return on investment needs to be evaluated with a cost-effectiveness analysis approach to determine the overall health benefit of a longer extended VR intervention. Future research will aim to evaluate whether this VR game can change perceptions and behavior around sun safety in people.

Esthetics and User Functionality

The esthetic elements incorporated into the VR experience were further discussed with the participants. All participants reported that they clearly identified the cancer character as a villain. Most participants found the voice satisfactory or would like the cancer voice to be darker or scarier (Multimedia Appendix 1). One participant commented, “I think it got the scary message across.” However, one participant thought the voice was too dark and said they would prefer not to have the emotion within the voice, and another participant identified it was slightly difficult to understand the darker voice.

Helpful information was provided throughout the experience, including a progress bar and pop-up game play information. Some participants understood the progress bar; however, those not familiar with gaming were unaware of its function. The treatment shooter was placed at the bottom of the game play screen and had an accompanying pop-up instruction (Multimedia Appendix 2). However, once the trigger was pressed, the treatment instructions disappeared, and some participants reported not seeing the instructions, as they eagerly pressed the trigger to commence game play. A treatment assistant character provided audio instructions and a narrative guide throughout the experience. Only 1 participant reported feeling lost at the start and would have liked more of an introduction commenting “It was clear that they needed to shoot the targets, but I did not understand why.”

Discussion

Addressing Challenges

Implementation challenges encountered by the research team while testing the VR headsets included maintaining power to equipment and hygiene issues when sharing VR headsets.

Charging Time and Batteries

If the VR headsets were used for more than 3-4 hours, recharging was required. If deployed at events in public settings, access to electrical supply or portal-powered charging stations must be considered to charge the VR equipment. The charging time for VR headsets was also more than 1 hour, which meant that additional VR headsets were required so that equipment could be rotated between charging and use. Hand controllers also require AA batteries, which may require replacement.

Hygiene and Headset Sharing

During the stakeholder testing (before the COVID-19 pandemic), we noticed that individuals who wore makeup on their face were transferring cosmetics onto the VR headsets, making them difficult to clean. We implemented disposable VR masks for every use, not just if the participant preferred to use one. Each mask is single use, and it is fitted over the ears and across the eyes before a headset is placed to prevent the participant’s facial skin from touching the VR headset.

The end user focus groups were conducted during the COVID-19 pandemic, and very low infectious rates were observed during the testing period. Extra precautions were implemented to maintain strict hygiene standards and prevent the spread of infectious diseases. Additional protocols included the headsets being wiped down using antibacterial wipes after each use as well as hand sanitizers being used by the participants both before and after using the VR equipment. Participants were reminded via email the day before the interview or focus group not to attend if they were feeling unwell. Staff members wore gloves when sanitizing the headsets, and social distancing was maintained during the end user focus groups, with chairs placed 1.5 m apart (Multimedia Appendix 3). This VR experience did

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not require much space, as it was a sitting experience; however, social distancing would have been much more challenging if participants were required to stand and move around a room.

We also noticed that when using the headset in a hot environment such as in Australia during spring, participants may sweat while using the equipment, which then transfers onto the VR equipment, making it undesirable for sharing. This also reinforced the need for cleaning protocols when sharing VR equipment.

Deployment Challenges

Although optimism for VR remains high, consumer adoption remains low, with only 11% of adults in the United States owning a VR headset [25]. Cost, a lack of games, and worries about motion sickness are reported as barriers to uptake [25]. In our study, 22% (4/18) of participants currently owned a VR headset, and only 3 of the 14 participants who did not own one reported that they might purchase one in the future. VR headsets are not widely available in the community, and participants reported that the VR experience was novel and exciting. Research has found high levels of public interest toward VR in the health care setting [26], and meta-analysis has shown that VR training interventions improve health professional education knowledge and skills [27]. Participants discussed settings where a VR headset would be particularly useful and identified hospitals and clinics as well as educational settings such as schools. A few participants mentioned that the VR experience was a good description of what is happening inside the body of a cancer patient and might be helpful for cancer education in hospitals. A previous study has illustrated that the use of relaxing VR content shown to patients with skin cancer before undergoing complex surgery reduced anxiety [28]. The ability to deploy VR experiences within health care settings is limited by access to VR equipment, and the opportunity for patients to access engaging VR health content is still futuristic.

With personal ownership of VR equipment low compared with smartphone devices, the audience reach for VR content is reduced compared with social media or app platforms. However, VR content can be reached by international markets through web-based stores, providing scalability for VR health interventions. For example, a free VR relaxation game had more than 40,000 unique users during a 2-year period, illustrating the potential scale and reach [29].

It should also be noted that VR content can often be ported into a 2-dimensional desktop PC experience. Although this undoubtedly increases the accessibility at this point in time, this approach may reduce the impact, engagement, and recall of the target audience [15,16]. These effects may also be amplified in our target audience of 18- to 35-year-olds, whose attention is highly competitive in the digital landscape. Assessing the longevity and impact of delivering sun protection messaging in a 2-dimensional versus 3-dimensional environment remains out of scope for this study and should be assessed in the future. In any case, a health intervention that uses a VR game to engage young adults will need a strong promotion strategy to successfully reach large audiences.

Finally, the participants in this study were a convenience sample, mostly female, and highly educated, which may limit the generalizability of the study findings.

Conclusions

Health messaging requires novel and engaging strategies to be effective in changing behavior and preventing cancer. We undertook a two-phase design approach to create a VR game, which immersed the player inside the body while the cancer grew. This design model allowed for refinement and improvements to be included throughout the process. The end user feedback identified improvements, which included extending the experience to a longer multistage game with visual transitions to other environments and interactions involving cancer causation. The implementation of the VR game identified challenges in sharing VR equipment and hygiene issues. Barriers to the deployment of VR health interventions at a population level were also recognized. This case study used an immersive VR technology platform and illustrated the design approach to create a cancer prevention message.

Acknowledgments

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Authors' Contributions

KD, JA, AG, HP, and EH had roles in the development of the VR game. The corresponding author had full access to all data in the study and the final responsibility for the decision to submit for publication. All authors reviewed and approved the manuscript for publication.

Conflicts of Interest

AG and HP are employees of Real Serious Games Pty Ltd, and KD is the director of Excite Science Pty Ltd.

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Multimedia Appendix 1
Virtual reality narrative. This audio file highlights the cancer voice and tone, and it also provides the starting narrative that was used to position the player inside the body where the interactive game began.
[AVI File , 3019 KB - games_v9i1e24652_app1.avi]

Multimedia Appendix 2
Virtual reality chemotherapy treatment. The top panel depicts the chemotherapy shooter, which was placed at the bottom of the screen and had accompanying instructions on use. The bottom panel shows how chemotherapy destroys the cancer cells.
[PNG File , 1779 KB - games_v9i1e24652_app2.png]

Multimedia Appendix 3
A focus group session. The sessions with end users were conducted in a large soundproof room to ensure that several people could concurrently complete the experience, which allowed participants to commence the focus group discussion together as a group after completing the virtual reality experience.
[PNG File , 1312 KB - games_v9i1e24652_app3.png]

Multimedia Appendix 4
Debriefing information poster providing an explanation of the gameplay experience and linking health facts.
[PDF File (Adobe PDF File), 345 KB - games_v9i1e24652_app4.pdf]

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Abbreviations

ABC: Appeal, Belonging, Commitment
SPF: sun protection factor
VR: virtual reality

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Original Paper

Pupillary Responses for Cognitive Load Measurement to Classify Difficulty Levels in an Educational Video Game: Empirical Study

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Abstract

Background: A learning task recurrently perceived as easy (or hard) may cause poor learning results. Gamer data such as errors, attempts, or time to finish a challenge are widely used to estimate the perceived difficulty level. In other contexts, pupillometry is widely used to measure cognitive load (mental effort); hence, this may describe the perceived task difficulty.

Objective: This study aims to assess the use of task-evoked pupillary responses to measure the cognitive load measure for describing the difficulty levels in a video game. In addition, it proposes an image filter to better estimate baseline pupil size and to reduce the screen luminescence effect.

Methods: We conducted an experiment that compares the baseline estimated from our filter against that estimated from common approaches. Then, a classifier with different pupil features was used to classify the difficulty of a data set containing information from students playing a video game for practicing math fractions.

Results: We observed that the proposed filter better estimates a baseline. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated (χ^2_{14}=0.05; *P*=.001); therefore, a Greenhouse-Geisser correction was used (ε=0.47). There was a significant difference in mean pupil diameter change (MPDC) estimated from different baseline images with the scramble filter ($F_{5,78}$=30.965; *P*<.001). Moreover, according to the Wilcoxon signed rank test, pupillary response features that better describe the difficulty level were MPDC (*z*=−2.15; *P*=.03) and peak dilation (*z*=−3.58; *P*<.001). A random forest classifier for easy and hard levels of difficulty showed an accuracy of 75% when the gamer data were used, but the accuracy increased to 87.5% when pupillary measurements were included.

Conclusions: The screen luminescence effect on pupil size is reduced with a scrambled filter on the background video game image. Finally, pupillary response data can improve classifier accuracy for the perceived difficulty of levels in educational video games.

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KEYWORDS

video games; pupil; metacognitive monitoring; educational technology; machine learning

Introduction

Overview

An *educational video game* (EVG) is a video game that provides learning or training value to the player. Potential contributions of video games cover each of the three main fields of psychology: the affective (awakening feelings), the connate (aggressive or impulsive behavior), and the cognitive (learning-related skills) [1].

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Video games have been demonstrated to be effective for improving working memory, mental rotation skills, and geometry performance [2]. Some of the effective features of educational video games include a clear goal, an adequate level of difficulty, quick-moving stimuli, and integrated instructions [3].

Several works have used EVGs to foster fraction understanding and to assess students [4,5]. However, our research focuses on the cognitive load (mental effort) generated by reasoning tasks [6] about math fractions; this is a direct way to measure the difficulty perceived by the EVG's player.

Video game difficulty refers to the amount of skill required by the player to progress through the game experience. Studying how to set an adequate difficulty level has attracted particular attention in the educational video games field [7,8]. Basic approaches to setting difficulty include allowing users to manually select levels and increasing the difficulty at a steady rate over the course of the game, with earlier levels being easier and later levels being harder [9]. Manually adapting difficulty or designing an incremental-difficulty solution could cause serious problems; for instance, the player may not know how they will perform before playing a given level, or the predefined change rate could be slower or faster than required by the player.

On the other hand, *dynamic difficulty adjustment* or *dynamic difficulty balancing* changes the game behavior according to the skill level of the players. For this purpose, the dynamic difficulty adjustment requires evaluation of the player's performance (through game scores, time, number of errors, player's decisions, etc) and adjustment of a set of game variables that regulate difficulty [10]. It has been shown that a dynamic approach that uses gamer behavior data presents better learning outcomes than an incremental difficulty approach [7].

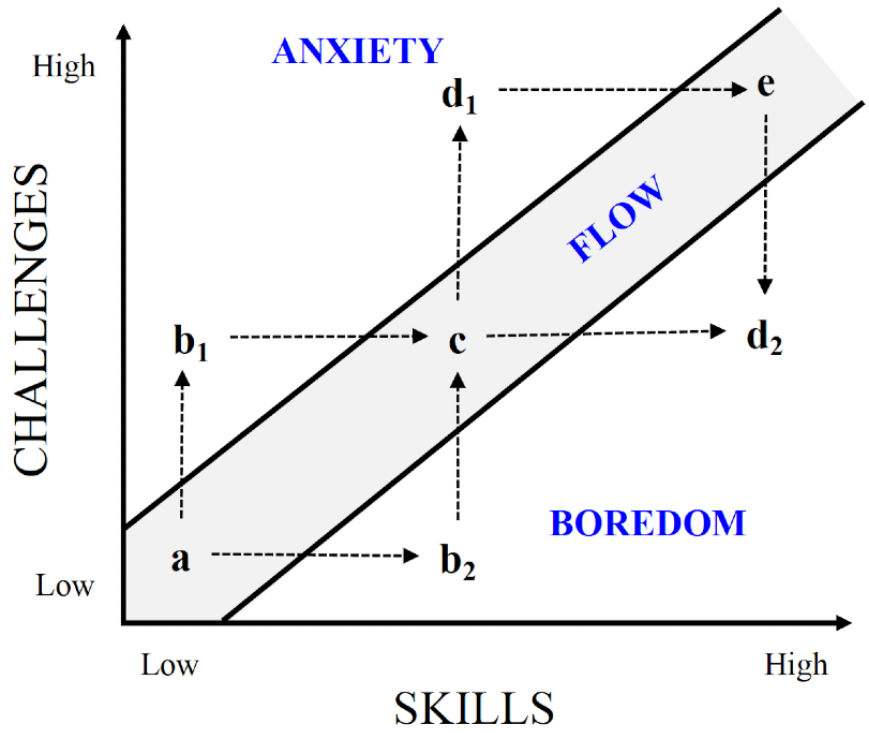
As a step toward finding an imperceptible difficulty control, this paper proposes to use pupil dilation to detect very easy (or hard) activities. It is known that pupil dilation reflects activity in the brain as cognitive load—that is, the total amount of mental effort (information processing) induced by reasoning tasks or involving memory resources [6,11].

Background

The Impact of Difficulty on Learning

The flow experience model, proposed by Csikszentmihalyi [12], marks an achieved balance of arousal-increasing and arousal-decreasing processes. As shown in Figure 1, the flow model describes this balance in terms of the fit between perceived challenges and skills: an activity wherein challenges predominate increases arousal; an activity wherein skills predominate reduces arousal. Thus, a synchrony of challenges and skills permits a state of deep involvement, while the pitfalls of either over- or under-arousal (ie, anxiety or boredom) are avoided [12].

Figure 1. Flow experience model of Mihaly Csikszentmihalyi [12].



The dynamic flow passing through states $a \rightarrow c \rightarrow e$ shown in Figure 1 is the optimal path for increasing difficulty. However, $b_1 \rightarrow d_1$ are states of anxiety that demand new learning skills to return to optimal flow. Moreover, $b_2 \rightarrow d_2$ are states of boredom that need more challenges to return to optimal flow.

Several studies have supported that the rate of change of pupil diameter is related to task difficulty.

Pupillary Responses

The eye can be seen as a camera, with the pupil as the eye aperture, and it involves the iris activity [13]. The iris movement is controlled by the activity of two muscles, the dilator and the

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sphincter. Sphincter activation causes the pupil to constrict (ie, miosis), and this is largely under parasympathetic control, while the dilator muscle receives mostly sympathetic innervation and causes the pupil to dilate (ie, mydriasis) [14].

Light has a relevant role in the retina and the pupil response. The size of the iris determines the amount of light that is captured by the system. The ambient light level largely determines the steady-state size of the pupil. Rapid increments in light flux on the retina cause a brisk constriction of the pupil. This constriction will depend on the size of the light stimulus, its luminance contrast, onset temporal characteristics, and location in the visual field [14].

Health factors also affect pupillary responses. Pupillary constriction is decreased in major depression [15]. Schizophrenia is associated with a significant decline in working memory capacity, and an additional moderate decline is associated with aging, but pupillary responses evoked by a working memory task were not related to schizophrenia severity [16]. Among other factors, the consumption of caffeine or alcoholic beverages was associated with significant increases in pupil size [17,18]. Finally, pupil dilation can be caused by amphetamines and diphenhydramine, and pupil constriction by clonidine and opioids [19].

For good observation of pupil response during EVG tasks, all these conditions must be carefully observed in the experiment design.

Cognitive Load and Pupillary Response

The cognitive load (mental activity) imposed by tasks has a pupillary response, known as a task-evoked pupillary response (TEPR) [20]. TEPRs occurs shortly after the onset of a task and subside quickly after the mental activity is terminated. The TEPR depends on several factors; for instance, the response is greater for novice participants doing an arithmetic task than for an expert because novices require more mental effort [21]. Then, through pupillometry (measuring the pupil diameter), one can decide whether a challenge is adequate for the skills of a learner (Figure 1); that is, we can balance a video game to maximize the learning outcomes.

Pupil diameter is widely used to study cognitive load. Researchers have studied this relationship in different tasks, such as driving a vehicle while listening to a dialog, reasoning through math exercises, memorizing numbers, and perceiving visual stimuli [6,22,23].

Concerning industrial areas, cognitive load has been used in automotive and healthcare applications to optimize user's decision-making tasks [21,24]. Most studies in these fields are oriented to discover how to preserve attention and mental work on primary tasks and how to reduce it on secondary tasks to avoid critical errors. In addition, cognitive load has been used in video game studies without significant results, mainly due to changes in screen luminescence.

Playing EVG involves memorization and reasoning tasks that are associated with cognitive load. This paper uses pupillary response data to assess cognitive load in educational video games.

Beatty [6] points out that pupillary responses occur at short latencies following the onset of mental processing and subside quickly once processing is terminated. Most of the latency is due to slow iris muscle constriction. Different features have been used to evaluate cognitive load with pupillary responses such as mean pupil diameter change (MPDC), average percentage change in pupil size (APCPS), peak dilation (PD), and latency to peak (LP) [13,24-26].

Estimating Pupillary Responses

Individual differences in pupil size have been well documented; for example, pupil size decreases linearly as a function of age at all illuminance levels, and students high in cognitive ability have a larger pupil size [27,28]. These differences must be considered when studying factors that dilate the pupil; for this purpose, researchers calculate a pupil baseline interval for each individual separately. Then, the pupil change is estimated by contrasting information from the baseline and testing intervals. In the baseline period, users fixate on a predefined screen before the stimulus is presented. Baseline duration ranges from 400 milliseconds to 10 seconds [6,29-32]. In general, the variation in the baseline duration should play no substantial role in reporting pupil dilation [33]. Unsworth et al [32] suggest that better results can be obtained by using a longer duration; hence, they use 5 seconds to estimate the baseline.

A common practice is to use a neutral image, either black, gray, or white [31,34]; a gray image is more effective to reduce screen luminescence [35]. Using a neutral image is good enough for controlled tests that use luminance-controlled images, but there are significant changes in pupil size due to luminance when participants play video games [36,37]. Studying the pupil dilation induced by mental activity when participants are exposed to environmental illumination changes is a challenge. For instance, several authors have reported that pupillary response features are directly correlated to cognitive load. Other authors, however, do not observe such correlations, and they suggest that this effect could be caused by luminance changes [38,39].

Obtaining a baseline for each trial rather than for a whole test session is a common practice [33]; this is an applicable solution for settings where the screen luminance remains stable for certain periods (eg, for a video game stage that is mainly dominated by the background). For these cases, the baseline is usually calculated from data generated by observing a scrambled image (ie, one image obtained by applying a scrambling scheme to a representative image in the period test).

Image scrambling [40] has two objectives: to transform a meaningful image into a meaningless or disordered image and to have the same mean intensity for the scrambled and original images.

The nonlinear relationship between luminance changes and pupil size is one of the main difficulties when studying cognitive load in real conditions. Wong et al [41] study four approaches (ignoring, excluding, compensating, or using pupillary light reflex features) to mitigate the luminance change in cognitive load measurements. They found that ignoring the luminance change is the worst option. This paper proposes an initial

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solution for studying cognitive load in real scenarios that is complementary to the approaches in the aforementioned study [41].

We hypothesize that a better baseline can be estimated from an image that maintains both the mean and local intensity. We tested grid scrambled images for obtaining the baseline. A grid scrambled image is generated by selecting a representative image within the measurement period, splitting it into a $n \times m$ grid (n columns and m rows), and finally, scrambling each region to conform the image.

The contribution of this paper is twofold: we propose a grid scramble filter to reduce the effect of screen luminescence, and we test the hypothesis that using pupillary response data improves the classification of easy (or hard) difficulty levels.

The rest of this paper is organized as follows: the Methods section describes the experimental setup, including materials, participants, metrics, and procedure; the Results section discusses the results of each experiment; and finally, the Conclusions and Further Work section concludes this paper.

Methods

The goal of this study is to analyze the pupillary response and gamer data for different difficulty levels in a math EVG to evaluate the significant differences in perceived difficulty for participants with intermediate math skills. Selected relevant features are used to classify difficulty.

Materials

An *eye-tracking* device, the "EyeTribe" model ET1000 with 60 Hz sampling frequency, was used in a screen (24" extended monitor) with a resolution of 1440 × 960 pixels, and both were connected to a laptop.

The eye tracker was located 50-60 cm from the participant's face. A calibration was done before each test/play session by using the EyeTribe software development kit (twelve points). To remove atypical values, a Hampel filter was used in the preprocessing stage.

To avoid pupil dilation caused by sunlight, the windows in the testing room were covered with blackout curtains, which have a high light-blocking effect. We used the same brightness and settings of the screen throughout. In addition, no sounds and visitors were allowed in the experimentation area.

The educational *Refraction video game* [42,43] was used in the experiments, as shown in Figure 2. For research, "Refraction" is of particular interest because it is open-access, it provides a natural context for students to create fractions through splitting, and the log data for the game allows the use of learning analytics methods to examine the splitting process in detail [43,44]. Moreover, the design of the game allows us to modify mathematical and game difficulty semi-independently [42].

This game focuses on teaching fractions and discovering optimal learning pathways for math learning. It let gamers bend, split, and redirect lasers to power spaceships filled with lost animals. The general integrated instruction is "Help free as many animals as you can by expanding your knowledge of fractions." As shown in Figure 2, game elements in Refraction are *origins*, which generate laser beams; *targets*, which receive the laser beams and contain spaceships with lost animals waiting to be released; *pipe bends* that change the laser direction; *2- or 3-way splitters* that split the laser into two or three equal parts (eg, the operation of a 3-way splitter over half of a laser is ½ ÷ 3 =); and *obstacles* that prevent the passage of any laser beams.

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Figure 2. The Refraction EVG developed by the research group of the Center for Game Science [42,43]. The game mechanic is to use the pieces on the right to split lasers into fractional pieces and redirect them to the target spaceships.



Four levels of the Refraction game were selected for experiments and organized into two worlds: world A (levels $L1_a$ and $L2_a$), and world B (levels $L3_b$ and $L4_b$). As shown in Table 1, levels that almost have the same number of game elements were grouped into the same world (ie, $L1_a$ and $L2_a$ have about the same difficulty level).

Table 1. Number of game elements in the selected levels.

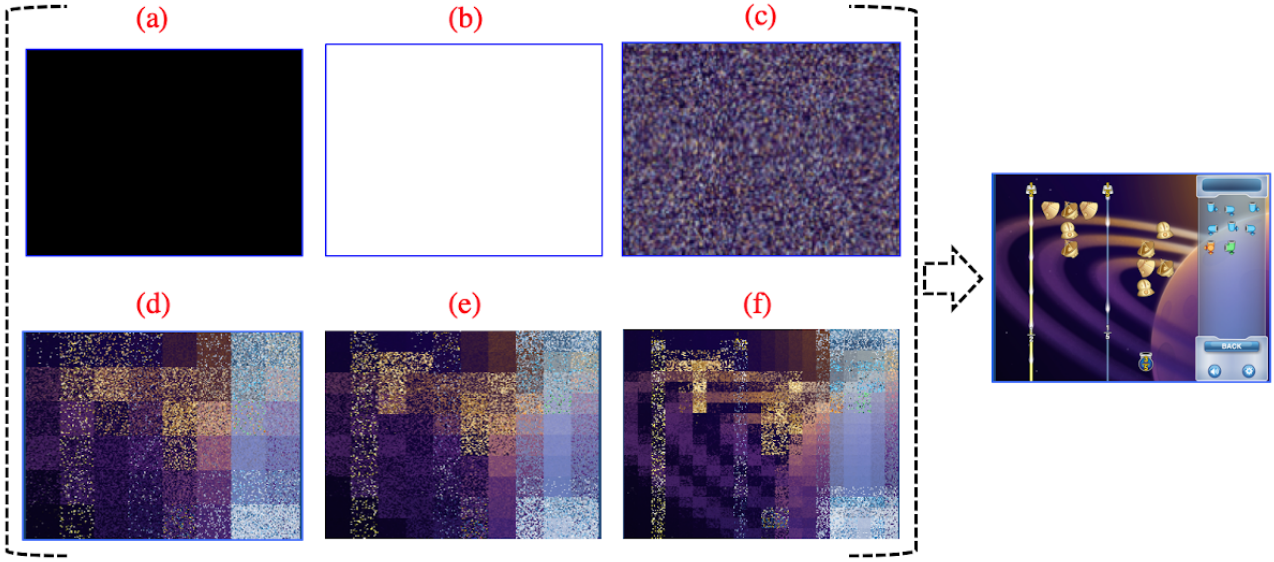
Element	Level			
	World A		World B	
	$L1_a$	$L2_a$	$L3_b$	$L4_b$
Origins	1	1	1	3
Targets	1	2	2	3
Two-way splitter (orange)	2	2	1	1
Three-way splitter (orange)	1	1	2	3
Pipe bends (blue)	3	3	3	3
Obstacles	10	10	13	10
Total elements	18	19	22	23

Experiment 1

The objective of this experiment was to select the best baseline image (ie, a baseline image without semantic information that results in a smaller pupil-size change after the transition from the baseline image to the in-test image). Instances of tested baseline images are shown in Figure 3; they included the widely used white, black, and scramble backgrounds, but also grid scramble images of different sizes: 8×6, 10×10, and 20×20.

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Figure 3. Baseline images tested. (Left) Baseline images can be uniform such as (a) black and (b) white, or can depend on the initial image like (c) scramble, (d) 8×6 grid scramble, (e) 10×10 grid scramble, and (f) 20×20 grid scramble. (Right) The in-test image.



Participants

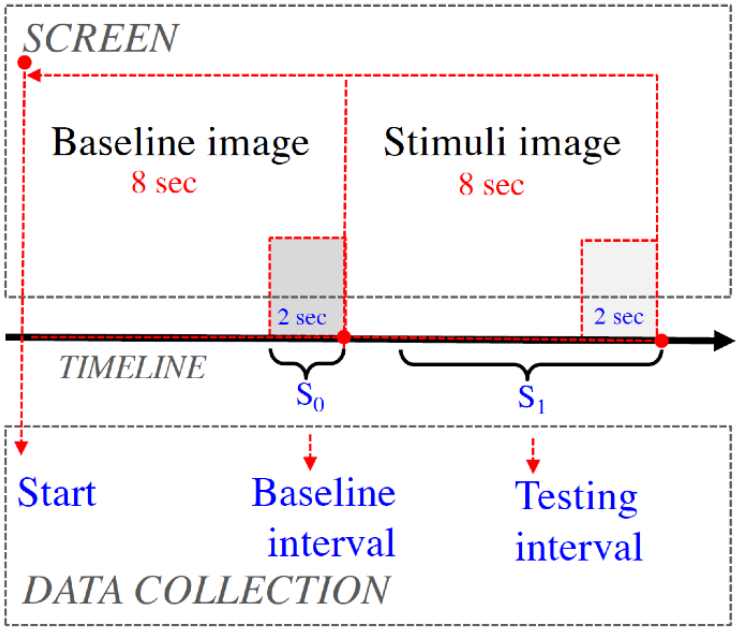
All participants were asked about their general health and were excluded if they wore contact lenses or glasses with more than one power, had eye surgery or abnormalities (eg, lazy eye, strabismus, nystagmus), or used medication or drugs. All participants were Hispanic and brown-eyed. Participants were not asked for personal information to preserve anonymity. A total of 14 volunteers (4 female, 10 male) between 16 and 37 years old (mean 21.81, SD 7.2) participated in this experiment.

Procedure

As illustrated in Figure 4, participants observed a randomly selected baseline image (an image from Figure 3) for 8 seconds (pupillary response data collected in the last 2 seconds are used as the baseline interval), and then they observed the in-test image for 8 seconds (pupillary data from the last 2 seconds are used as the testing interval).

The MPDC is used to select the best baseline image (the MPDC definition is shown in Table 2). This procedure was repeated until all the baseline images were shown to participants.

Figure 4. The procedure used to generate pupillary response data for evaluating baselines images. First, the baseline image was shown on the screen for 8 seconds, and then the in-test image was shown.



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Table 2. Pupillary and gamer features studied in this experiment.

Feature	Description
TE	*Total errors* (TE) is the number of events performed in the wrong way (eg, the laser beam value does not match with the input value) on a level.
TC	*Time to complete a stage* (TC) is the time required to complete a given level.
CP	*Number of changes of position* (CP). A *change of position* is defined as the movement of a game element once it has been introduced in the gameplay—the area where the video game elements are dragged and dropped.
A	*Attempts* (A) is the number of attempts used by the gamer to complete a given level.
MPDC	The *mean pupil diameter change* is obtained by averaging the relevant data points in the measurement interval (time of the stage) and subtracting the mean diameter obtained in the baseline period [24-26].
PD	*Peak dilation* (PD) is defined as the maximal dilation obtained in the measurement interval time of the level [13]. First, mean baseline is established, then the single maximum value from the set of data points in the measurement interval time of level is selected.
LP	*Latency to peak* (LP) reflects the amount of time elapsed between the beginning of the measurement interval and emergence of peak dilation [13].
APCPS	*Percentage change in pupil size* (PCPS) is calculated as the difference between the measured pupil size and a baseline pupil size divided by the baseline pupil size [22,31,45]. The *average PCPS* (APCPS) is the average of PCPS in the measurement interval time of the selected level.

Statistical Analysis

After Mauchly's test of sphericity, repeated-measures analysis of variance was performed on the normally distributed variables among MPDC values to explore the difference between the black, white, scramble, scramble 8×6, scramble 10×10, and scramble 20×20 baseline images. The Bonferroni test was used to make post hoc pairwise comparisons.

Experiment 2

The objective of this experiment was twofold: to evaluate which features are more related to the difficulty level, and to test the classification accuracy obtained by using different subsets of features. Studied features (both pupillary and gamer) of the video game levels ($L1_a$, $L2_a$, $L3_b$, and $L4_b$) are defined in Table 2.

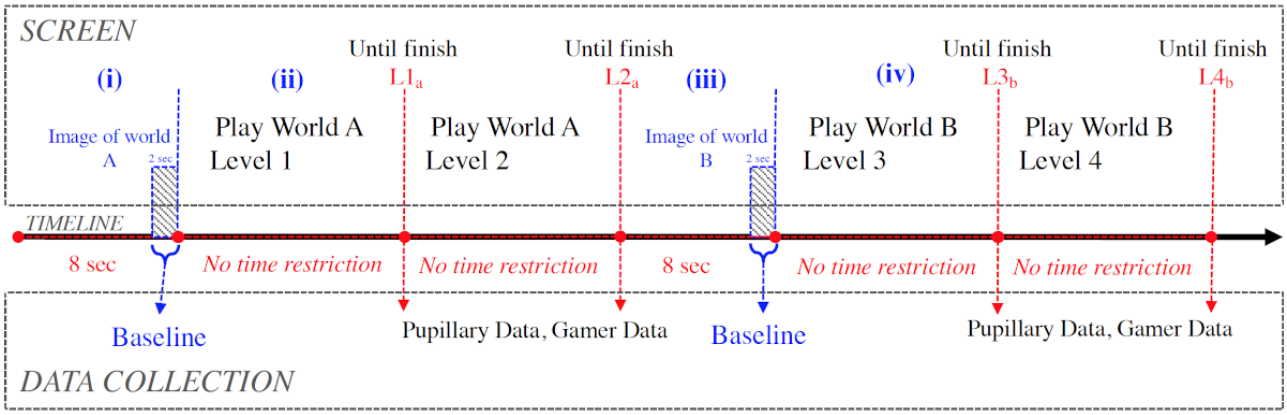
Participants

A total of 20 volunteers (9 female, 11 male) between 23 and 31 years old (mean 27.16, SD 2.6) participated in experiment 2. As in the first experiment, we did not include volunteers with some characteristics that would make pupil-size estimation difficult. None of the subjects who participated in experiment 2 also participated in experiment 1.

Procedure

As shown in Figure 5, the procedure consists of four phases: (1) participants observed the baseline image of world A for 8 seconds; (2) participants played the world A levels ($L1_a$ and $L2_a$) without time restrictions; (3) participants observed the baseline image of world B for 8 seconds; and finally, (4) they played the world B levels ($L3_b$ and $L4_b$) without time restrictions. The pupil baseline was estimated from the data of the last 2 seconds before playing a new world. Pupil size and gamer behavior data were collected along with each play session.

Figure 5. The procedure used to evaluate features against difficulty levels in World A (easy), World B (hard).



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After obtaining features, all information was integrated into a data set $\tau = \{(X_i, Y_i), i = 1,...,n\}$, where X_i corresponds to the uniform-length vector containing features $X_i = (TE_i, TC_i, CP_i, A_i, MPDC_i, PD_i, LP_i, APCPS_i)$ and Y_i corresponds to the label associated to each level difficulty of the world A and world B. Each register of this data set is generated from a player and a single level. The following sets were defined: $G = \{TE, TC, CP, A\}$, which includes all game behavior data features, and $S = \{MPDC, PD, LP, APCPS\}$, which includes all pupillary features. Let $G' \subseteq G$ and $S' \subseteq S$ be the sets of features with a significant difference between worlds A and B.

From the 20 participants, 3 (15%) were randomly selected, and their registers in τ were used to train a random forest classifier [46] using different sets of features. Random forest classifier was selected because it is an ensemble meta-algorithm that improves accuracy and avoids overfitting by training on different random samples of the data. Registers in τ associated with the rest of the participants were then used as the testing set.

Statistical Analysis

Features were tested for normality; in this case, the Shapiro-Wilk test was used (because of the low size of the sample), Results show that the variables are not normally distributed. Then, the Wilcoxon signed rank test was used to detect significant differences in variables. Differences between values were considered significant when $P<.05$.

Results

Experiment 1

Mauchly's test of sphericity indicated that the assumption of sphericity had been violated ($\chi^2_{14}=0.05$; $P<.01$); therefore, a Greenhouse-Geisser correction was used ($\varepsilon=0.47$). The results show that there was a significant difference between MPDC estimated from different baseline images ($F_{5,78}=30.965$; $P<.001$).

Table 3 shows the descriptive statistics for MPDC calculated for each baseline image. As expected, the 20×20 scrambled filter has the lowest average MPDC (0.32 pixels) as it more closely resembles the original image. Post hoc analyses using the Bonferroni post hoc criterion for significance indicated that there were no MPDC differences for different grid sizes, but there were significant MPDC differences between the group of images generated by the grid scrambled filter, and the group of conventional images used to estimate the baseline (white, black, and scrambled). We choose the 8×6 grid scramble operation for generating baseline images in experiment 2 because there are no differences in MPDC between grid scramble images, and it better obscures the meaning of the in-test image.

Table 3. Results for the baseline image test (experiment 1). Different superindices indicate significant intergroup differences.

Baseline image	MPDC[a] (pixels), mean (SD)
White[1]	3.356 (2.122)
Black[2]	−1.754 (1.452)
Scramble[3]	1.620 (0.746)
Grid scramble 8×6[4]	0.471 (0.891)
Grid scramble 10×10[4]	0.455 (1.392)
Grid scramble 20×20[4]	0.320 (0.856)

[a]MPDC: mean pupil diameter change.

Experiment 2

We did not find any feature with significant differences in measurements between levels of the same world, neither in the levels of world A ($L1_a$, $L2_a$) nor in the levels of world B ($L3_b$, $L4_b$). However, significant differences between worlds were found for the following features: TE between world A (median 0.00) and world B (median 2.50) ($z=-2.9$; $P=.004$); TC between world A (median 43,486) and world B (median 83,970) ($z=-3.198$; $P=.001$); MPDC between world A (median 2.25) and world B (median 2.90) ($z=-2.159$; $P=.03$); and PD between world A (median 5.1) and world B (median 18) ($z=-3.587$; $P<.001$). Table 4 summarizes the statistics for pupillary and gamer features and the Wilcoxon signed rank results.

On the other hand, Table 5 summarizes the accuracy of the random tree classifier. As can be seen, the PD feature alone gives an accuracy of 62.5%. The best accuracy was obtained by using the $G' \cup P'$ features, with an accuracy of 87.5%.

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Table 4. Median values for pupillary and gamer measurements, and the Wilcoxon signed rank results.

Feature	World A, median	World B, median	*z*	*P* value
TE	0.00	2.5	−2.900	.004
TC	43,486	83,970	−3.198	.001
CP	0.00	1.00	−0.382	.70
A	0.50	1.00	−0.282	.78
MPDC	2.25	2.90	−2.159	.03
PD	5.10	18.00	−3.587	<.001
LP	40.50	51.50	−0.973	.33
APCPS	0.135	0.136	−0.926	.36

Table 5. Results for a random forest classifier using different sets of features.

Set	Features	Accuracy (%)
G	TE, TC, CP, A	75.0
G'	TE, TC	75.0
P	MPDC, PD, LP, APCPS	50.0
P'	PD	62.5
G' ∪ *P'*	TE, TC, PD	87.5

Discussion

Experiment 1

Pupil-size changes at the beginning of the EVG (when going from the baseline image to the in-test image) can cause the participant's pupil to expand. A change caused by the screen luminescence would hide the change caused by the cognitive load produced by the reasoning task. This change was analyzed using the MPDC in experiment 1; it was found that baseline images with uniform colors (white and black) result in larger changes in pupil size (Table 3). The sign values of the MPDC are aligned with the optics of the human eye, as it is posited that pupil size increases when the intensity of environmental light decreases (in the case of black or white images); these changes occur even if baseline images resembles the general illumination conditions of the testing scenario such as the scrambled operation.

One could expect that a grayscale image, with the same average intensities as the in-test images, gives a good baseline estimator. Results of experiment 1 show that the conventional scrambled image (which has about the same intensities) just gives a rough estimation of the baseline. Alternatively, the proposed grid scrambled operation better estimates the baseline in comparison to the conventional scramble image. A possible explanation is that retinal ganglion cells (the output neurons of the retina) adapt to both image contrast (the range of image intensities) and to spatial correlations within the scene, even at constant mean intensity [47]. Hence, predicting the pupil size of an individual in different image scenes is challenging. John et al [48] propose a calibration protocol where the participant sees uniform slides of varying grayscale intensities in the range 0-255. We state that a better model could be found by using local and global information from the images.

Experiment 2

Many studies have shown that splitting objects is a promising way to teach fractions [43,49]. In any context, splitting items into halves is much more common than dividing into thirds; this could explain why the students prefer halving and struggle with creating thirds [43]. The Refraction game uses the process of splitting to teach fractions. As shown in Table 1, levels of world A (easy) have fewer 3-way splitters than levels of world B (hard). This means that participants must solve more operations that involve thirds in world B. The difficulty of the Refraction game not only depends on the mathematical operations but on the spatial difficulty. The spatial difficulty is directly correlated to the number of sources and targets; the number of source/target elements is smaller in the world A than in the world B. Results also evidence this change of difficulty, as we observed statistical differences in features G'—including TE and TC.

A random tree classifier that only uses the best game features, G', only gives an accuracy of 75.0%. This accuracy was improved to 87.5% by using the *peak dilation*. The maximal dilation obtained in the measurement interval is a natural feature of many factors that dilate the pupil, including the cognitive load.

Pupillary features can be classified into subtractive (those that eliminate individual differences by subtracting the baseline value from the measurement interval, such as *MPDC*, *PD*, and *LP*) and divisive (those that calculate a ratio of a measurement value to baseline, such as *APCPS*). Subtractive features can be categorized into *size-related*, such as *MPDC* and *PD*, or *time-related*, such as *LP*. Results show that the subtractive size-related features, *MPDC* and *PD*, better describe the difficulty level.

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Hunicke [50] states that difficulty adjustments must be implemented in a way such that users do not perceive difficulty changes. However, gamer data are recorded after human perception of difficulty; that is, a control that uses gamer data collected after the player finished each level could not completely fulfill the requirement of being imperceptible.

The proposed approach improves the accuracy of classification of the perceived difficulty to 87.5%, in contrast to 62% with only pupillometry. These results are aligned to other studies that suggest the relationship between pupil change and the level of a game; for instance, by using the Akaike Information Criterion, Strauch et al [51] propose that the pupil change is a quadratic function of the levels of Pong.

Video game difficulty adjustment is game data–dependent (ie, different games require different features). We argue that a generic framework for dynamic difficulty adjustment could be designed by fusing generic game features (such as score, elapsed time, etc) with the information provided by pupillometry. In this way, we can take advantage of ocular data as a general, noninvasive, near real-time option to sense the user perception of difficulty.

In a traditional pupillometry experiment, the researcher maintains tight control over luminance while manipulating a specific cognitive variable. Reilly et al [52] conducted the reverse approach (ie, holding cognitive task demands constant while manipulating luminance). We believe that the reverse approach must be used to obtain a model of the participants' pupil size in the initial calibration stage by using the grid scrambled images, and then a subtractive approach should be used during the gameplay stage.

Conclusions and Further Work

This paper proposes a grid scramble filter to obtain a baseline image that reduces the effect of the screen light reflex on a participant's pupil size. This filter simulates both the local and the mean luminance of a given image. To hide the meaning of an image, the 8×6 grid scramble filter can be used for tests that reasonably keep the same background in each interval. We consider that a more general baseline can be obtained by modeling luminescence factors that affect pupil size. Such a model could be used to estimate cognitive factors that affect the pupils in any setting (eg, a commercial video game).

Gamer data are a valuable resource for estimating the difficulty of EVGs, but adding cognitive load data measured by pupillary response data improves the accuracy of classifying the difficulty of game levels.

Using the human perception features from ocular data such as blinks, eye-fixations, and eye-saccade to measure the cognitive load may improve the classification accuracy of difficulty levels and gather imperceptible changes that gamer data can omit [53,54].

A key issue with approaches that estimate a baseline, like the proposed one, is that indoor light conditions and monitor brightness must be the same during the game time. Playing a game in specific conditions is restrictive; to address this, we are working on a model that relates luminescence to different screen configurations (instead of a baseline) This approach can be used in virtual reality headsets. The proposed approach can be included in a more elaborated calibration stage that tests different models of pupil change due to luminance, as in a previous study by Lara-Alvarez and Gonzalez-Herrera [55].

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Conflicts of Interest

None declared.

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Abbreviations

A: attempts
APCPS: average percentage change in pupil size
CP: number of changes of position
EVG: educational video game
LP: latency to peak
MPDC: mean pupil diameter change
PD: peak dilation
TC: time to complete a stage

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TE: total errors
TEPR: task-evoked pupillary response

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Original Paper

Game-Based Learning Outcomes Among Physiotherapy Students: Comparative Study

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Abstract

Background: University teaching methods are changing, and in response to a classical teacher-centered approach, new methods continue to strengthen knowledge acquisition by involving students more actively in their learning, thus achieving greater motivation and commitment.

Objective: This study aimed to analyze the degree of satisfaction of physiotherapy students who used a board game–based approach, as well as to compare the difference between traditional and gamification teaching methods and their influence on the final evaluation of these students.

Methods: A comparative study was conducted. Participants were physiotherapy students who were enrolled in the subject of "physiotherapy in geriatric and adult psychomotricity" (n=59). They were divided into two groups (experimental [n=29] and control [n=30] groups) through convenience sampling. The experimental group received gamification lessons, where the students performed different tests adapted from Party&Co, and the control group received traditional lessons. A total of 16 theoretical lessons were received in both groups.

Results: The scores in the final examination of the subject were higher in the experimental group (mean 7.53, SD 0.95) than in the control group (mean 6.24, SD 1.34), showing a statistically significant difference between the two groups (P=.001).

Conclusions: Overall, the "Physiotherapy Party" game not only stimulated learning and motivated students, but also improved learning outcomes among participants, and the improvements were greater than those among students who received traditional teaching.

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KEYWORDS

gamification; board game–based approach; health sciences; physiotherapy; teaching innovation

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Introduction

Defining Concepts: Gamification Versus Game-Based Learning and Others

The term "gamification" emerged on the academic scene in the late 1990s, but was not commonly used in education and training until 2010 [1,2]. This concept describes an approach to teaching, in which students explore relevant aspects of games in a learning context designed by teachers and students in order to add depth and perspective to the experience of playing games. In this sense, this state-of-the-art teaching approach involves fun, engagement, significant learning, and interactive entertainment, and is defined as a type of gameplay that constitutes learning outcomes [2].

However, it is common to confuse different terms in these new trends, such as gamification, serious games, and game-based learning, which have sometimes been used interchangeably [1]. While gamification refers to the implementation of game mechanics in day-to-day processes or nongaming contexts, including the use of game components in different scenarios with no intention of creating a game [3,4], serious games are defined as games where the main goal is learning (not entertainment) and where designers do have the intention of creating a game [5]. Having said that, this may get slightly confusing because game-based learning also uses the aforementioned game-like elements and mechanics, but the differences are in gamification, which takes the entire learning process into a game [6]. Gamification typically involves the use of game mechanics or strategies (eg, rules and rewards), as well as visual and game-thinking elements (eg, cards and gameboards) to engage people and motivate and promote learning [7]. The most popular gamification tactics include (1) providing specific goals, (2) providing feedback, (3) showing progress, (4) providing badges of achievements, (5) using levels for incremental challenges, (6) giving a storyline, (7) allocating points, and (8) using a scoreboard [8].

In terms of making these elements more appealing, the rules are geared toward both processes and objectives, which might be fundamentally unplayable only by themselves. A recent systematic review of empirical evidence concluded that gamification has an impact on learning outcomes through motivation, academic achievement, and social connectivity. Gamification, used as part of a robust engagement strategy, is a motivator, both intrinsic and extrinsic, that plays a key role in promoting student engagement in learning. Additionally, there is a connection between learning achievement and engagement. The more engaged students are, the greater their achievement, and social comparison can explicitly promote social connectivity and a sense of relatedness among students [9].

Despite the promising data on gamification, there is limited experimental research and there are apparent limitations, such as lack of control groups, short interventions, and nonvalidated questionnaires [8]. According to a review by Arruzza et al [10], gamification appears to have several benefits for the general population, registered health professionals, undergraduate students in fields not related to health sciences, and undergraduate students in health sciences. Nevertheless, further research is needed to know if this results in increased levels of knowledge retention, application, and professional competence [10].

Background

The lack of interaction between students and teachers, as well as between students themselves, is one of the most problematic scenarios nowadays [11,12]. In this context, where only student-content interaction exists, the frequency and intensity of educators' influences on students using gamification are far greater [13]. In recent years, there has been a growing interest in how gamification can have a beneficial impact on student engagement in different educational settings [3,14,15], with a focus on learning through incentives [16]. In the current literature, however, there is scant evidence that connects gamification to traditional academic results or focuses on data from game-based initiatives as a source for education analytics [17]. Apart from that, it has been shown that the integration of game-based activities [18,19] does improve student enjoyment compared to traditional teaching approaches and provides more opportunities for class participation, hence increasing motivation and helping students learn more about the subject [20,21].

Consequently, university teaching approaches are adapting as educators aim to attain both better learning and more productive teaching [22]. State-of-the-art approaches, such as the use of gamification, seek to strengthen the acquisition of knowledge by engaging students in their own learning process as a response to a traditional approach, thereby gaining greater encouragement and confidence [23]. Thus, the aim of this study was to measure the learning experience of third-year physiotherapy students using the "Physiotherapy Party" game about geriatric and adult psychomotricity, which is a teaching game designed based on a gamification approach to assist them in their learning experience and help them prepare for their examination, as well as assess the results in the final evaluation of the subject. Our hypothesis was that the use of a game-based teaching approach will improve the motivation of students and involve them in their learning, even if it requires investing time to set up the game. Since the students who use the game will learn in a progressive and meaningful manner, the time and preparation will result in a higher grade in their final evaluation.

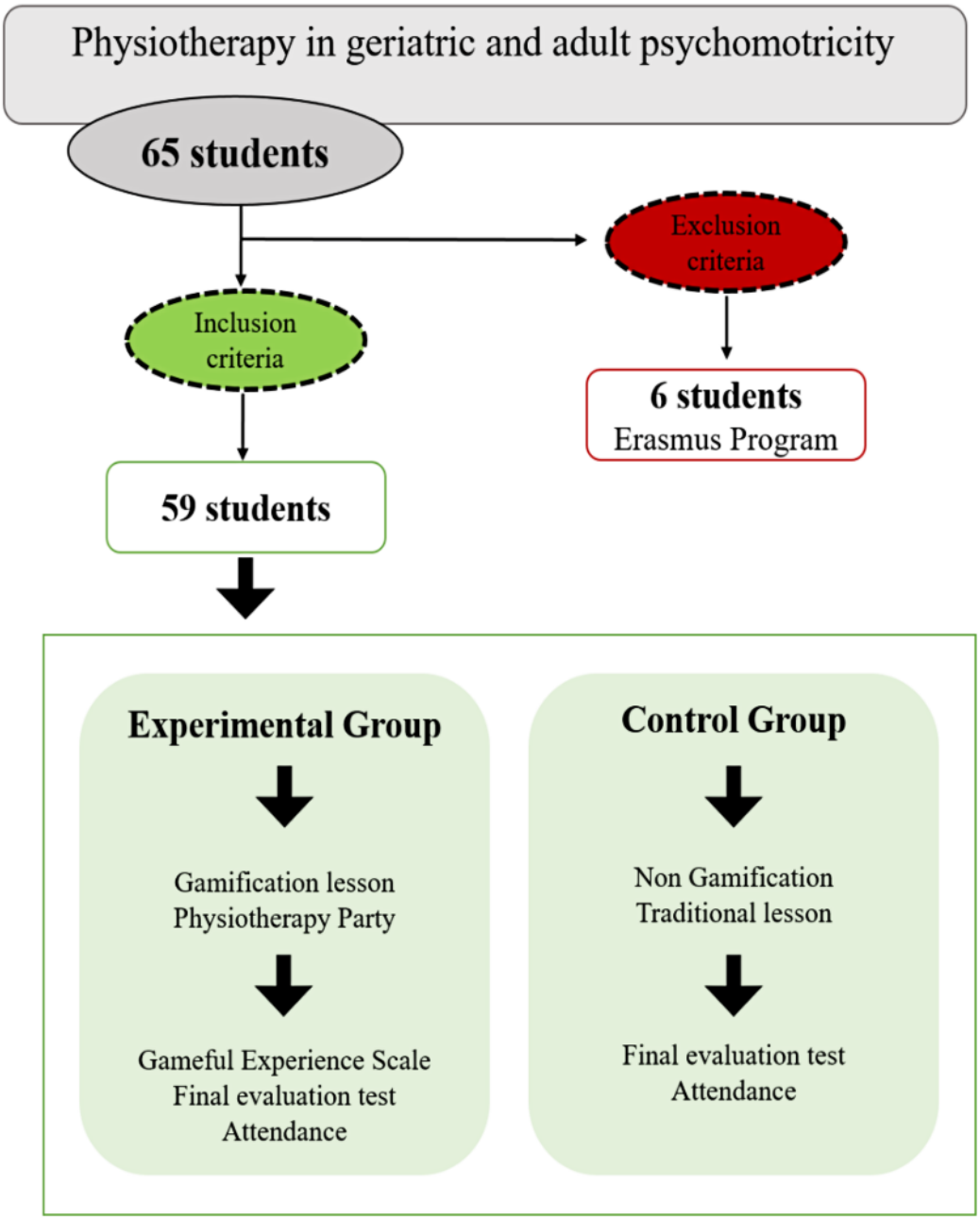
Methods

Study Design

A comparative design was used to study the experiences and results of a group of students. Of 65 students enrolled in the subject of "physiotherapy in geriatric and adult psychomotricity," 59 were allocated into two different groups through convenience sampling. The groups were an experimental group (n=29) and a control group (n=30) (Figure 1). The experimental group (15 females and 14 males) received gamification lessons, and the control group (18 females and 12 males) received traditional lessons. A total of 16 theoretical lessons were received in both groups.

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Figure 1. Flow diagram of participants.



Setting and Participants

The research population of this study consisted of physiotherapy students from the University of Almeria, and the study was carried out in the second semester of the 2018-19 academic year at the Faculty of Health Sciences. “Physiotherapy in geriatric and adult psychomotricity” is a compulsory subject of six European Credit Transfer and Accumulation System (ECTS) credits taught in the second semester of the third year, which has become essential for the aging population. This subject consists of theoretical and practical classes, which are divided into groups of 15 to 20 students. Its contents introduce students to the care of the elderly population; the physiology of aging and physiotherapy in traumatological and rheumatological conditions in the elderly population; neurological, cardiovascular, and respiratory diseases in the elderly population; cognitive and affective disorders in the elderly population; endocrine and nutritional disorders in the elderly population; urinary incontinence in the elderly population; and physical activity in the elderly population.

Rules and Game Design of the Physiotherapy Students’ Party Game

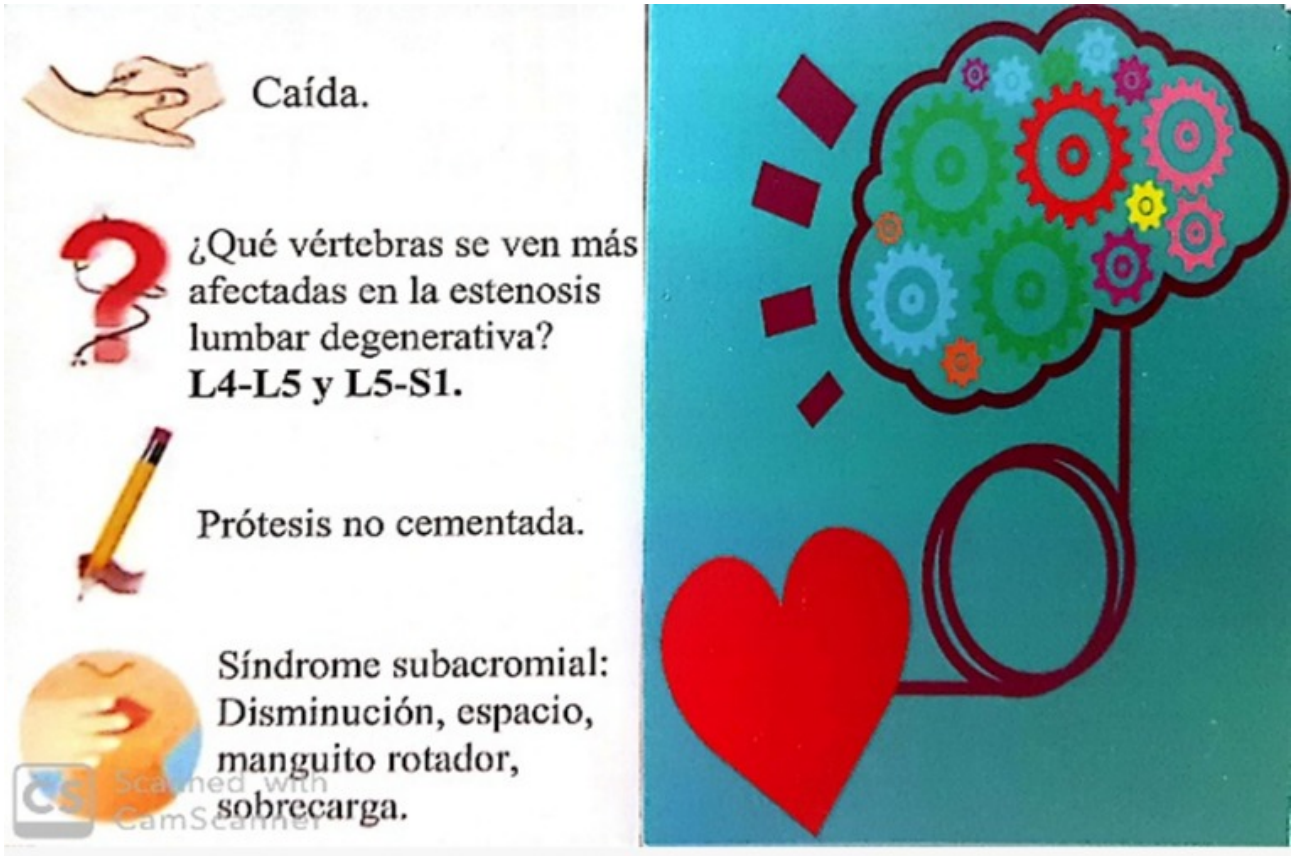
The “Physiotherapy Party” game was named “Guadaña&CO” (Figure 2). The aim of the game was for participants to win each one of the different challenges in mime, questions, forbidden words, and drawings to obtain cards in the main boxes and perform the final test. Students were divided into five groups to compete in the game (one group of five students and four groups of six students). These students had to show their knowledge in the subject to pass each of the four different tests on each card (Figure 3), which included the contents of the subject.

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Figure 2. Physiotherapy Party game.



Figure 3. Card used in the game.



Playing "Physiotherapy Party"

Once all elements of the game, such as the game board, tokens, dice, timer, card holder, and instruction sheet, were organized by two lecturers (GMT and PR), students were asked to create their own cards of each topic studied in class, which covered all the content of the subject. The purpose was to work and memorize basic concepts of the subject by making cards. Following the instructions of the "Physiotherapy Party" game, players first have to throw the dice and move their token through the game board. Then, they have to perform each of the tests that appear on the chosen cards from the corresponding box. The team has 30 seconds (controlled by an hour-glass timer) to carry out each one of the tests. Finally, the team that gets the last card out of each main box and performs the final test correctly wins.

Variables and Data Collection

We collected sex and age as sociodemographic variables, as well as the attendance for gamification and traditional lessons,

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the grades in the final theoretical examination in the subject, and the game experience.

Measures

The Gameful Experience (GAMEX) scale was used to assess the experience of physiotherapy students in the game [24,25]. This scale consists of 27 items graded on a Likert scale ranging from 1 (never) and 5 (always). The items are distributed into six different dimensions, which include enjoyment, absorption, creative thinking, activation, absence of negative effects, and dominance. The total Cronbach α value was .855. Particularly, the Cronbach α value was .843 for the enjoyment dimension, .898 for the absorption dimension, .865 for the creative thinking dimension, .790 for the activation dimension, .841 for the absence of negative effects dimension, and .860 for the dominance dimension [25].

Final Evaluation

A 34-question test with four multiple-choice options on theoretical contents of the subject was developed for the final evaluation.

Procedure

Before starting lessons with both groups, students were allocated on the basis of their subgroup enrolment. While subgroups 1 and 3 were assigned to the experimental group, subgroups 2 and 4 were assigned to the control group and were not informed of the "Physiotherapy Party" game. The difference between the two groups was that the experimental group used the "Physiotherapy Party" game, whereas the control group did not use this game. There were no further differences (evaluation, lessons, contents, lecturer, etc). Students were informed about the aim of the investigation, as well as the confidential and anonymous treatment of their data. Once informed consent was obtained, the gamification lessons and traditional lessons were started. The study data were collected in June 2019, after the last gamification and traditional lesson, as well as after the final theoretical examination.

Data Analysis

The data analysis was carried out using the statistical software SPSS version 22 (IBM Corp). First, a descriptive analysis was conducted from the results. Central tendency and dispersion measures were determined for the quantitative variables, while the frequency and percentage were analyzed for the categorical variables. In contrasting the hypothesis between qualitative and quantitative variables, after showing a normal distribution with the Kolmogorov-Smirnov test, the Student *t* parametric test was used for independent samples.

Ethical Considerations

This study was approved by the Ethics Committee of the University of Almeria (Spain) (EFM-28/19). All participants were informed about the aim of the study prior to participation. Participants were informed about the confidentiality of their data, and all consent forms were signed. All ethical aspects established in the Declaration of Helsinki were followed at all times.

Results

Sociodemographic Characteristics

Fifty-nine physiotherapy students from the University of Almeria participated in this study. Table 1 shows the sociodemographic characteristics of the participants. The total sample consisted of 59 students (55.9% [n=33] were female and 44.1% [n=26] were male), with a mean age of 23.37 years (SD 4.91 years).

Table 1. Sociodemographic characteristics of the participants (N=59).

Characteristic	Experimental group	Control group
Participants, n (%)	29 (49.2%)	30 (50.8%)
Sex, n (%)		
Female	15 (51.7%)	18 (60.0%)
Male	14 (48.3%)	12 (40.0%)
Age (years), mean (SD)	22.10 (3.39)	24.60 (5.83)

Attendance for Gamification and Traditional Lessons

Out of 16 theory and gamification sessions, the mean attendance by students in both groups was 10.85 lessons (SD 4.84), while that in the experimental group was 12.66 (SD 3.06) and that in the control group was 9.10 (SD 5.60). Both groups showed a significant difference in relation to their attendance for the traditional lesson (t_{57}=3.009, *P*=.004).

Results in the Final Qualification

Regarding the final qualification of the theoretical examination, the final mean score was 6.87 (SD 1.32) for both groups, while that in the experimental group was 7.53 (SD 0.95) and that in the control group was 6.24 (SD 1.34). Final scores in both groups showed significant differences (gamification was either applied or not applied) (t_{57}=4.208, *P*=.001).

GAMEX Scale

Considering the GAMEX scale (Table 2), the scores were above average in all the dimensions, except negative effects. Specifically, the mean scores were as follows: enjoyment, 25.93 (SD 4.01; range 6-30); absorption, 20.03 (SD 5.87; range 6-30); creative thinking, 14.10 (SD 3.42; range 4-20); activation, 15.10 (SD 2.89; range 4-20); absence of negative effects, 5.14 (SD 2.23; range 3-15); and dominance, 12.79 (SD 3.66; range 4-20).

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Table 2. Data of each Gameful Experience (GAMEX) scale dimension by sex.

Dimension	Score, mean (SD)		*P* value
	Men	Women	
Enjoyment	26.00 (3.94)	25.87 (4.22)	.93
Absorption	19.43 (5.47)	20.60 (6.35)	.60
Creative thinking	14.57 (3.22)	13.67 (3.65)	.49
Activation	15.00 (2.74)	15.20 (3.12)	.86
Absence of negative effects	4.79 (2.75)	5.47 (1.64)	.42
Dominance	13.64 (3.05)	12.00 (4.10)	.24

Discussion

Principal Findings

The aim of this study was to analyze the degree of satisfaction of students after using the "Physiotherapy Party" game in geriatric and adult psychomotricity, as well as to compare the two different teaching methods (traditional lessons and gamification lessons) and their impacts on the final evaluation.

To the best of our knowledge, there is no previous evidence on the use of this classic family board game adapted for teaching in physiotherapy. This innovative educational game is trendy, enjoyable, and entertaining as the first dimension of the GAMEX scale showed. As our participants reported in the satisfaction questionnaire, it enabled them to remember and apply knowledge more easily. In the same line of results, previous reports on the use of gamification in nursing studies support these findings, such as using an escape room among nursing students [22,26], in which gamification helped to acquire competencies by positively shaping the teaching-learning process. Gamification has been shown to successfully increase students' motivation to learn and to be an additional resource based on student engagement and meaningful learning in education [27]. In this sense, Cain [28] pointed out that it can be used to have a more positive student experience as it immerses students in their learning process as active participants. Among medical students, Kinio et al [29] developed a platform for learning that may be more enjoyable and serve as a complement to traditional lectures. These platforms might be used to do quick assessments in learning activities, such as the game "Kahoot!" [30], which have led to a paradigm change in classrooms, promoting self-learning among students.

In addition, these kinds of games promote creative thinking, as reflected in the results of this study and those of other studies [31-34]. In line with the findings of Gómez-Urquiza et al [22], games, such as Escape Room and the one suggested in this study, help students in their day-to-day practice when it comes to thinking critically, as they have to bear in mind all potential solutions to their problems, which enhances their overall decision-making skills [35]. Additionally, this gamification-like approach promotes the application of knowledge acquired in the course of using the platform [22].

Analyzing other dimensions of the gaming experience, the participants did not feel frustrated in most situations. These results are similar to those found by other studies [36], where only a few students showed frustration and confusion.

Regarding the learning results, there was a significant difference between both groups, and the group involving gamification had the best results. In line with these results, other studies have shown the benefits of such game-based learning approaches over traditional strategies [37]. Game-based strategies have been shown to encourage learning and thus result in dramatically improved student performance [38]. In the end, game-based teaching approaches enhance student motivation while increasing student participation and providing effective feedback [39]. These interventions have been shown to have a beneficial impact across educational programs for learners, with improved grade point averages [40], increased positive student perception of learning [41], better understanding of concepts [42], and decreased course drop-out rates [43] compared to the findings among students who used more traditional approaches.

Methodological Considerations

There are several limitations to be taken into account in the results of this study. First, the generalization of our results should be considered cautiously, as participation in the study was voluntary and sample selection was through convenience sampling. Furthermore, the sample was not randomized and only 59 students participated. Additionally, owing to the nature of the intervention, the participants could not be blinded. Besides, the GAMEX scale has been validated in a digital environment and has not been validated for a nondigital game, although it was previously used with good consistency [44,45]. Despite these drawbacks, the limited number of studies exploring the influence of games in the health sciences is one of the strengths. In this sense, there is no evidence of the use of gamification in physiotherapy, and therefore, it offers an opportunity as a new research line in innovative teaching. Moreover, it should be emphasized that the use of the "Physiotherapy Party" game improves academic performance with respect to traditional education. However, this innovative teaching approach initially requires a considerable amount of time for the teacher to prepare game materials, rules, and game dynamics. Students must also prepare game cards based on the content of the subject, although they are indeed working and studying, which promotes a gradual and meaningful learning process. Conversely, enjoyment was not measured at each session. It would therefore be interesting to measure this dimension at each session in order to assess the appropriate

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number of sessions for the use of this innovative teaching method.

Conclusions

The "Physiotherapy Party" game was shown to be a learning activity that allows students to remember and implement the knowledge and professional competences acquired in the subject more easily. In addition, it motivates students to study, thus improving their attendance in these classes.

This study confirms that gamification as an alternative to conventional approaches can be considered an interesting and state-of-the-art approach for teaching physiotherapy, which can be used at the same time to improve knowledge among university students.

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Authors' Contributions

Innovation design and proposal: GMT, RA, and MR; game and rule adaptation: MRA, NSL, and PR; game elaboration: MMSJ and GMT; final review of the game: MRA and PR; implementation of the proposal: GMT and PR; draft of the manuscript: GMT and PR; final version review: GMT, MRA, RA, NSL, MMSJ, PR, and MR.

Conflicts of Interest

None declared.

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Abbreviations

GAMEX: Gameful Experience

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Original Paper

Managing Game-Related Conflict With Parents of Young Adults With Internet Gaming Disorder: Development and Feasibility Study of a Virtual Reality App

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Abstract

Background: Individuals with internet gaming disorder (IGD) report facing family conflicts repeatedly because of their excessive internet gaming. With recent advancements in virtual reality (VR) technology, VR therapy has emerged as a promising method for the management of various psychiatric disorders, including IGD. Given that several risk and protective factors for young people with addiction can be influenced by their interpersonal context, the potential utility of VR-based apps for managing family conflicts needs to be examined with reference to IGD management. However, few studies have evaluated potential treatment modules related to interpersonal conflict management, such as emotion regulation and taking the perspective of others.

Objective: This preliminary study aims to examine the potential use of a VR-based app in the management of game-related conflicts with parents of young adults with IGD and matched controls.

Methods: In total, 50 young male adults (24 with IGD and 26 controls) were recruited to participate in the study. We developed a virtual room where game-related family conflicts arise. Using this room, participants completed 2 VR tasks that required them to express anger and then implement coping skills (ie, risk/benefit assessment of stopping a game and taking parents' perspective) to deal with negative emotions in interpersonal conflict situations and to decrease one's gaming behavior.

Results: The results showed that immersion in our VR app tended to provoke negative emotions in individuals with IGD. In addition, after a risk/benefit assessment of stopping a game, the response of stopping a game immediately increased significantly in the IGD group, suggesting that patients' gaming behavior could be changed using our VR program. Furthermore, in individuals with IGD, longer gaming hours were associated with a lower level of perceived usefulness of the coping skills training.

Conclusions: The findings of this study indicate that our VR app may be useful for implementing more desirable behaviors and managing gaming-related family conflicts in individuals with IGD. Our VR app may offer an alternative for individuals with IGD to learn how a vicious cycle of conflicts is developed and to easily and safely assess their dysfunctional thoughts behind the conflicts (ie, perceived unreasonable risks of stopping a game and thoughts acting as a barrier to taking the perspective of others).

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KEYWORDS

internet gaming disorder; family conflict; coping behavior; virtual reality

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Introduction

Background

Internet gaming disorder (IGD), defined as the persistent and recurrent use of the internet to engage in games, can lead to significant psychological distress and impairment in daily social functioning [1]. Given that social, behavioral, and neurobiological development continues until young adulthood, addiction in these periods could have a more striking effect on young populations [2,3]. Therefore, intervention and prevention targeting groups at risk for developing gaming-related problems may reduce the burden of the disease and provide lifelong benefits.

With global efforts to inform effective practice, appropriate therapeutic recommendations for IGD are being made [4]. The most commonly reported approach is a combination of various interventions, including cognitive behavioral therapy (CBT) [5,6], motivational enhancement therapy [7], and pharmacotherapy [4,8]. In addition, with recent advancements in virtual reality (VR) technology, the use of VR coupled with CBT has become a viable treatment option for IGD [9]. However, current VR treatments for patients with IGD have been developed in the context of substance abuse treatment, with a focus on aversive conditioning [9,10] and cue exposure [11]. Thus, few studies have evaluated other potential treatment modules, such as emotion regulation and interpersonal conflict management, which are critical for the management of IGD symptoms. Therefore, it is essential to build an evidence base for other specialized modules for individuals with IGD, which can be implemented using VR technology.

In some East Asian countries, as parental influences may continue even into young adulthood [12,13], young adults as well as adolescents are likely to experience game-related family conflicts. Youth with IGD could experience more difficulties related to handling such conflicts because they often exhibit avoidance coping styles, characterized by the denial of problems or their impact on them [14-16]. Thus, when confronted by their parents who ban gaming, they would deny and refuse to discuss their gaming problems with their parents, which can, in turn, contribute to a harmful cycle of problematic gaming [17]. Therefore, there is a need for specific therapeutic recommendations that not only take into account a repetitive pattern of conflict escalation in the family context but also seek to improve problem-solving skills to resolve these conflicts.

Interpersonal conflict management is one of the clinical domains of psychiatric treatment in which VR-based CBT has been applied increasingly [18,19]. In this context, although some researchers have developed anger-provoking VR [20], an intervention for anger management is still scarce. Studies on VR-based CBT have demonstrated the usefulness of VR in learning social skills via role-playing scenarios [21,22]. Such studies introduced exercises for challenging social contexts (eg, a virtual school) in a stepwise manner, thereby requiring patients to master a series of social skills (eg, starting a conversation and recognizing peers' emotions) within a VR program [23]. Interactive VR, defined as a dyadic interaction that allows feedback from an avatar, is also known to benefit VR-based CBT [24]. Combining interactive VR with role-playing interpersonal scenarios can help individuals with IGD learn coping skills to handle family conflicts.

The VR scenario we chose for training coping skills in family conflict management is based on the risk/benefit assessment of addictive behavior. From the perspective of risk/benefit analysis, it can be assumed that if the perceived benefits of addictive behavior are weighted more heavily than are perceived risks, then people will continue to engage in such behavior. In accordance with this conjecture, previous studies demonstrated that the tendency to weigh risks more than benefits was predictive of risky and gambling behavior [25]. Moreover, recently, a behavioral intervention for cigarette smokers focusing on a personalized analysis of the risk/benefit of quitting (eg, the risks are the increase in negative affect and reduced ability to concentrate, and the benefits are better health, well-being, and finances) was found to be effective in improving smoking cessation outcomes [26]. Most of the relevant studies seem to focus primarily on perception of the general aspects of risks and benefits of addictive behavior, suggesting that this kind of intervention to treat addictive behavior is feasible in clinical settings [27]. As it is more helpful for adolescents/young adults to set a goal that is shortly and proximally framed, focusing on the risks and benefits of harmful behavior within a short time frame could be more effective. As such, our VR content was implemented to create a perception of stopping gaming immediately, focusing on risk-benefit analysis in a short-term framework.

The second scenario for coping skills training dealt with how individuals cope with negative emotions in interpersonal conflict situations. As disputes on gaming time in the family of individuals with IGD could lead to severe conflict or even violence among family members, emotion regulation in such situations seems to be particularly important for individuals with IGD. Previous research has suggested that one type of emotion regulation involves understanding the current situation from the perspective of others [28]. Thus, in this study, conflict situations escalating into violence were reproduced, and participants were asked to apply taking the perspective of their virtual parents.

Objectives

Given this background, the objective of this study is to examine the potential of a VR-based app designed to help young adults with IGD to manage game-related conflicts with their parents in a sample of individuals with IGD and matched controls. A virtual room, presumed to be the participants' own, was developed, in which family conflicts were simulated. To determine whether our VR contents were capable of eliciting negative emotions (ie, anger), the participants engaged in a family conflict situation and were then encouraged to express their anger to their virtual parents who banned gaming. As a part of problem solving–focused training, we implemented the following 2 coping skills: evaluating the perceived benefits and risks (or disadvantages) of stopping the game immediately and taking the perspective of parents on their gaming behavior. As preliminary data on the potential role of VR as a promising approach in the management of IGD, we investigated whether

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patients with IGD expressed greater anger compared with matched controls and whether their response could be changed after experiencing the coping skill training within our VR program. Finally, we tested whether behaviors in response to our VR program were associated with the severity of IGD and other relevant clinical measures (eg, gaming frequency and motivation for changing gaming behavior).

Methods

Sample Size (Power)

Power analysis for an independent *t* test was conducted using the G*Power [29] program to determine the necessary sample size with an α of .05, a power of 0.80, a large effect size (f=0.8), and two tails. The results suggested a desired sample size of 26 participants in each group, totaling 52 subjects, to detect the group difference in our dependent measures.

Recruitment

Young Asian male adults (24 with IGD and 26 controls) were recruited from the local community using web-based advertisements. As men are known to have a higher prevalence of IGD than women and to avoid gender-specific confounding factors related to emotion expression and coping skills affecting the results, only male participants were recruited [30-32]. All participants were interviewed by a clinical psychologist for IGD diagnosis according to the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* [1]. All enrolled participants with IGD were at the time addicted to at least one of the popular internet games in South Korea (eg, Battle Grounds, League of Legends, and Overwatch). For the controls, reviews of history were performed to confirm whether the participants had ever been diagnosed with IGD. In addition, the controls were screened for a family history of psychiatric disorders; no one had a history of any psychiatric illness in first-degree relatives. The exclusion criteria for all participants were current use of psychotropic medication and any history of substance use disorder, neurological or neurodevelopmental disorder, major depressive disorder, bipolar 1 disorder, and psychotic disorder, as determined using the Mini-International Neuropsychiatric Interview [33]. However, 2 participants with depression were included in the IGD group. Ethical approval was obtained from the institutional review board of Yonsei University Gangnam Severance Hospital. Informed consent was obtained from all participants.

Measures

Estimated full intellectual functioning (IQ) was obtained using the short form of the Wechsler Adult Intelligence Scale-Revised [34]. Internet gaming behavior was measured in terms of frequency of use (eg, hours of use per week). Participants were asked to rate their current gaming craving on a visual analog scale (VAS), which represents the severity of craving on a 100-mm horizontal line, ranging from no craving at all (left side) to extreme craving (right side). The result is a score on a continuous scale, ranging from 0 to 100.

Readiness to change internet gaming behavior was assessed using a modified version of the readiness to change questionnaire [35]. The modified questionnaire contained 12 items on a 5-point scale, ranging from *strongly disagree* (−2) to *strongly agree* (2), with higher scores representing a higher readiness to change. The total score serves as an index of the motivation to stop playing internet games.

The presence questionnaire (PQ) [36] and the simulator sickness questionnaire (SSQ) [37] were used to measure the users' experience with our system. PQ is a measure of users' presence in VR, which is a psychological state of *being there*. Presence can enhance users' active engagement in content, involving their senses and capturing their attention. SSQ assesses simulator sickness resulting from the discrepancy between simulated visual motion and the sense of movement coming from the vestibular system. Simulator sickness is negatively correlated with users' enjoyment of VR programs.

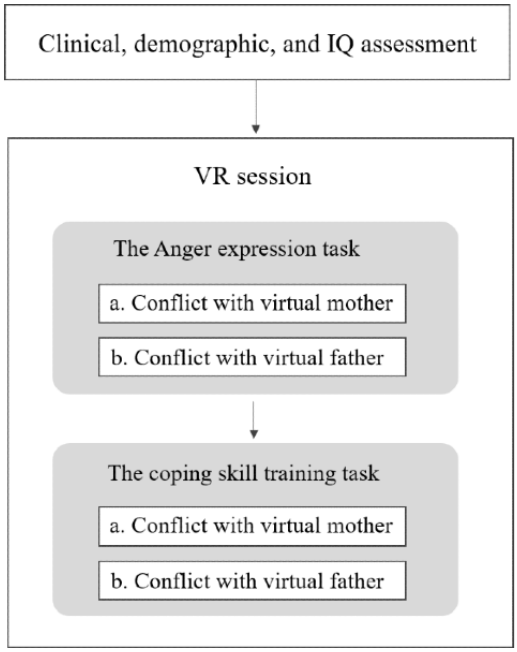
Procedure

After each participant was informed of the purpose of the study and they consented to participate, the IQ assessment was conducted, and data on demographic and clinical characteristics were collected. Subsequently, the participants began the VR session. This study was conducted for approximately 20 to 30 min, with each of the 2 scenarios taking about 10 to 15 min. Their time to completion differed depending on how quickly each participant responded to the tasks in each scenario and which responses were chosen.

As shown in Figure 1, all participants began with the anger expression task, but tasks with the virtual mother or father were randomized and counterbalanced among participants to control for order effects.

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Figure 1. Experimental procedure. The order of tasks on conflicts with the virtual mother and father was counterbalanced. VR: virtual reality.

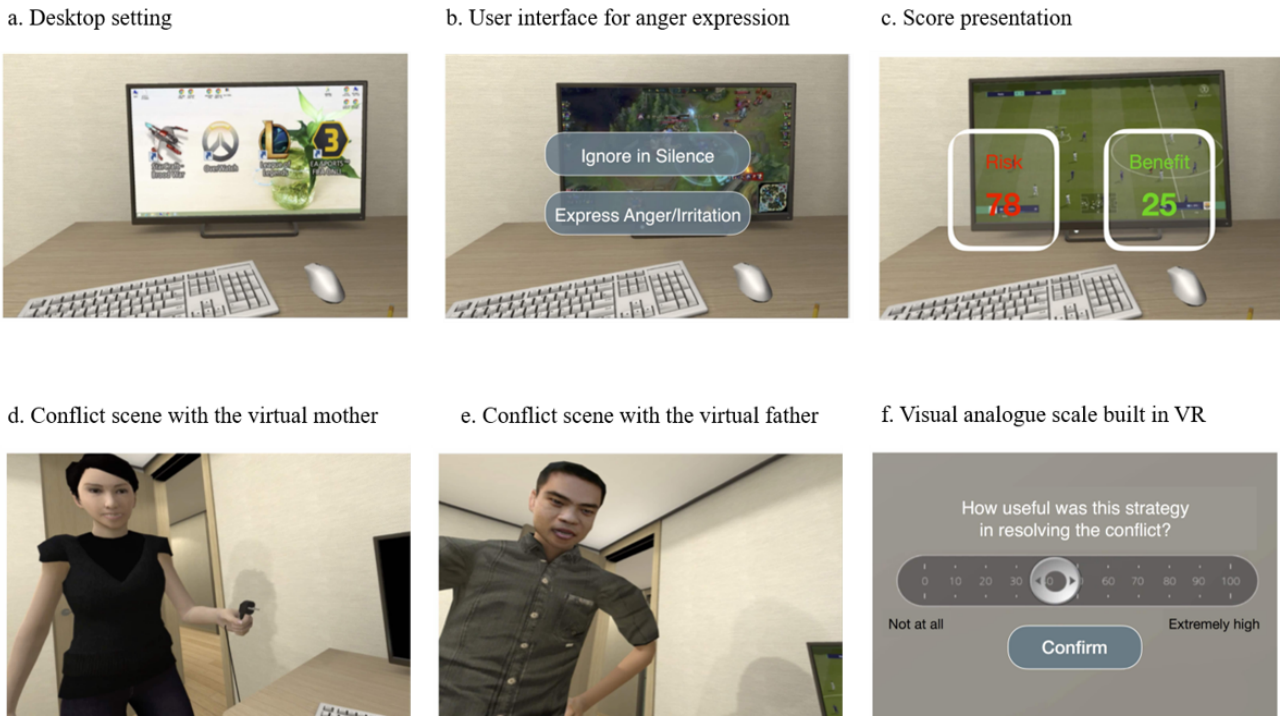


Virtual Reality

We developed our own VR scenarios. Our VR scenarios emphasized the development of motivation for change based on the implementation of CBT principles by enabling the participants to access dysfunctional thoughts behind the conflicts (ie, perceived unreasonable risks of stopping a game and thoughts acting as a barrier to perspective-taking) easily.

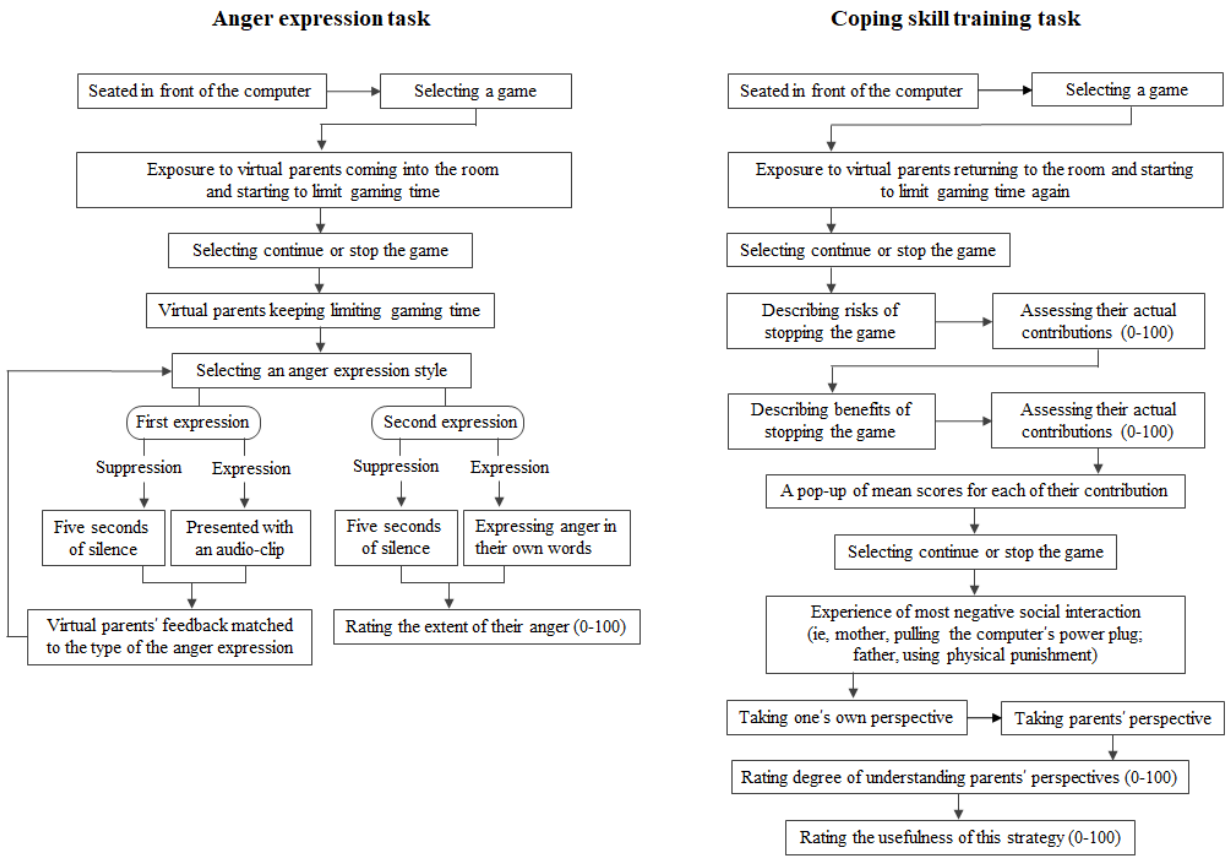
Participants were guided through the following 2 sets of VR tasks in a virtual room, presumed to be the participants' own room: (1) an anger expression task and (2) a coping skill training task (see Figure 2 for screenshots of the virtual environment). Figure 3 presents a flowchart of the scenario. At the beginning of all tasks, participants found themselves seated in front of a monitor displaying internet game icons (eg, StarCraft, Overwatch, League of Legends, and FIFA Online; Figure 2). The participant watched a video clip of their own choice played on the monitor in this VR program. The scenario continued depending on the task content. Every task ended by rating the usefulness of the strategy in resolving the conflict on a VAS built within the VR program (Figure 2).

Figure 2. Screenshots of the virtual environment. VR: virtual reality.



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Figure 3. Flowchart of the virtual reality scenario.



Anger Expression Task

In the anger expression task, virtual parents would enter the room and begin compelling the participants to stop the game immediately. Next, the participants were offered a choice of whether to *continue* or *stop* the game. Regardless of which behavior they selected, the scenario would continue with another round of nagging from the parents to stop the game. Participants were then instructed to express their perceived anger about the 2 instances in which they were being forced to end the game. They were offered only a choice-based response format to express their initial anger (ie, suppression: *ignore in silence* or expression: *express anger/irritation*; Figure 2). If they selected *suppression*, the scenario continued to the next scene after 5 seconds of silence. If they selected *expression*, corresponding audio clips of a male actor's voice were played. Following the completion of the initial expression, parents' feedback was delivered, the content of which matched the participants' anger expression response (see Multimedia Appendix 1 for the scripts of the clips). When expressing anger for the second time, participants were allowed to choose the anger expression style and were allowed to express their anger verbally to the parents' avatars. At the end of each expression, the participants rated the extent of their anger experience on a VAS built within the VR program (0=not at all, 100=extremely high; Figure 2).

Coping Skill Training Task: Risk/Benefit Assessment and Perspective-Taking Task

In the coping skill training task, the virtual parents returned to the room, asking the participants why they had not stopped the game yet and attempting to limit their gaming time again. Participants were again offered a choice to either *continue* or *stop* the game immediately. Subsequently, they were instructed to employ the 2 coping skills of risk/benefit assessment and perspective-taking. Specifically, they were asked to provide an example of benefits and disadvantages of stopping the game immediately (ie, "What are the benefits/disadvantages of stopping the game immediately? Please describe an example") and to assess the extent of the effect of each example on them (ie, "How much effect will the example you described have on you?") using a VAS built within the VR program. They were asked to report as many examples as possible. These items were listed one at a time until they wished to move to the next question. After viewing the mean scores of their effect assessment (Figure 2), they were finally offered the choice of whether to *continue* or *stop* the game immediately. As before, regardless of their choice, the scenario continued with the parent's pushing the participant to stop the game again. However, this time, the participants experienced the most negative social interaction in the VR situation. For example, the virtual mother turned off the game by pulling the computer's power plug (Figure 2) or the virtual father used physical punishment by spanking the participant (Figure 2).

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For the second coping skill, the participants were asked to talk about the parents' behavior from their own perspective, followed by talking about it from the parents' perspective. Subsequently, they rated the extent to which they were able to understand their parents' perspective using a VAS built within the VR program.

The VR system consisted of a desktop computer (with the Microsoft Windows 10 operating system, an NVIDIA GeForce GTX 970 graphics card, and a 16 GB RAM graphics memory) and an Oculus Rift head-mounted display (Oculus VR; HD resolution of 1080×1200 per eye with a 51.6 diagonal field of view, a 3 degrees of freedom tracker for head rotation, and built-in headphones). The Oculus Touch controller was used for interactions with executable objects and avatars during the VR experience. The microphone built into the VR headset gathered verbal data of users' self-speech in real time. Three-dimensional virtual environments included a virtual house and appliances using Autodesk 3D max and were integrated with Unity software. User data such as selected responses and selection time, head movement, hand gestures, speech contents, and speaking time were recorded and stored in the main server computer. This system allowed the therapist to track patients' performance and analyze behavioral information.

Statistical Analysis

We tested differences between groups on demographic and clinical variables using independent *t* tests. In addition, we conducted repeated measures analysis of variance (ANOVA) to test whether the 2 groups differed in the variables of interest in each VR scenario. To further examine the significant main effects and interactions, we conducted *post hoc* analyses, with Bonferroni correction at $P<.05$. Finally, Pearson correlation coefficients were used to investigate the relationships between the behavioral responses of the virtual environment and clinical variables. Statistical differences were considered significant at $P<.05$. All analyses were conducted using SPSS 23.0 (IBM Corporation).

Results

Comparison of Clinical Symptom Measures Between IGD and Control Groups

Table 1 shows the results of a two-tailed independent *t* test between the IGD and control groups in demographic and clinical variables. There were no differences in age, education, and IQ between groups. As expected, the IGD group had higher scores on gaming craving, IGD symptoms, and internet gaming hours per week.

Table 1. Demographic and clinical characteristics of participants with internet gaming disorder versus healthy controls.

Characteristics	IGD[a] (n=24), mean (SD)	Healthy controls (n=26), mean (SD)	*t* test (*df*)	*P* value
Age (years)	21.78 (2.33)	21.65 (1.83)	−0.22 (48)	.83
Education (years)	14.12 (1.19)	14.61 (0.94)	1.62 (48)	.11
IQ	119.54 (10.11)	122.04 (9.72)	0.92 (48)	.36
Gaming craving (visual analog scale)	6.87 (1.46)	0.85 (1.05)	0.41 (48)	<.001
Severity of IGD[b]	7.29 (1.08)	N/A[c]	N/A	N/A
Internet gaming hours per week	50.12 (13.27)	1.99 (1.30)	−18.41 (48)	<.001
Presence Questionnaire	102.29 (16.83)	114.92 (12.93)	2.99 (48)	<.001
Simulator sickness questionnaire	7.45 (7.68)	4.53 (5.73)	−1.53 (48)	.13

[a]IGD: internet gaming disorder.

[b]Severity of IGD was assessed using the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, criteria for IGD, providing a total score between 0 and 9.

[c]N/A: not applicable.

For scores on the PQ, there was a significant difference between the IGD and control groups ($t_{48}=2.99$; $P<.001$). As internet games played among participants with IGD have high-quality graphics and animations, the VR environment and interactions might be perceived as less realistic and natural in the IGD group. Regardless of the group difference, the overall mean score was above the midpoint of the scale, indicating that participants experienced a high level of presence in the respective virtual environment.

The average score on the SSQ corresponded to lower levels of simulator sickness than the established norms for the SSQ [37]. An independent *t* test reported no significant difference between the 2 groups in their SSQ scores ($t_{48}=-1.530$; $P=.13$). This shows that both the IGD and control groups had similar VR experiences.

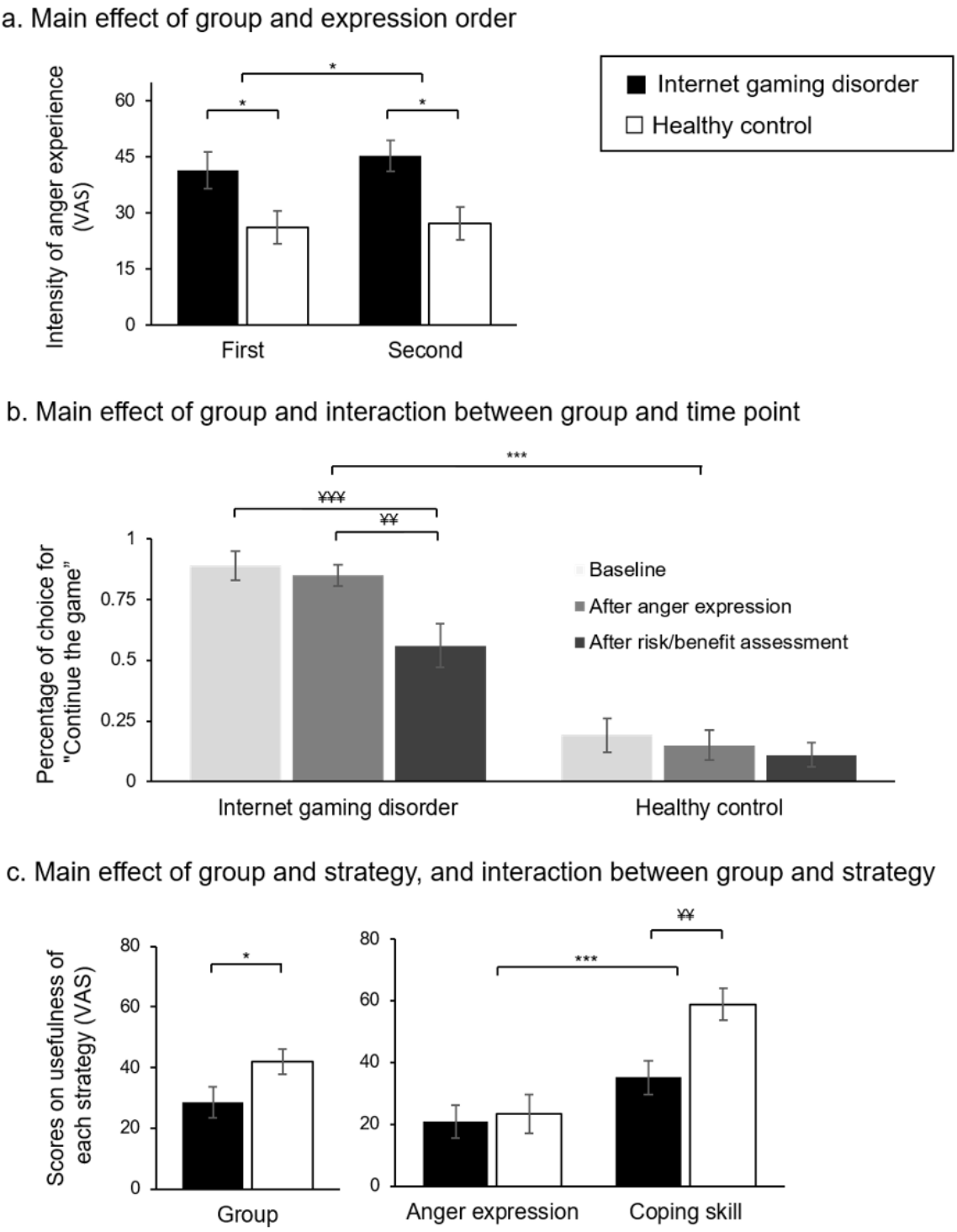
Anger Expression Style and Intensity of Anger Experience

Figure 4 shows the results of a three-way ANOVA of the 2 dependent variables in the anger expression task. The intensity of anger experience revealed a significant main effect of group ($F_{1,48}=8.154$; $P=.006$), target ($F_{1,48}=4.278$; $P=.04$), and expression order ($F_{1,48}=5.221$; $P=.03$; Figure 4). However, no main or interaction effects were observed for the anger expression style. These results indicate that the IGD group experienced higher levels of anger than the control group, the virtual father produced significantly higher anger than the virtual

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mother, and the second anger expression produced significantly higher anger than the first expression.

Figure 4. Results of analyses of 3 dependent variables. (a) Mean ratings for the intensity of the anger experience; (b) mean percentage of response choice for "continue the game"; (c) mean ratings for usefulness of each strategy. Error bars represent SE of the mean. *: group or condition effect, *P<.05, **P<.01, ***P<.001; ¥: significant two-way interaction, ¥¥: P<.01; ¥¥¥: P<.001.



Risk/Benefit Assessment of Stopping the Game Immediately

A 3-way ANOVA on the number of perceived risks (disadvantages) and benefits of stopping the game immediately revealed a significant interaction between group and evaluation type ($F_{1,48}$=10.157; P=.003), indicating the tendency of the control participants to report significantly more benefits than risks (t_{25}=−3.277; P=.003). Difference scores (the number of benefit items minus the number of risk items) were used in the correlation analyses. Among individuals with IGD, higher

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scores, indicating more benefits than risks, were significantly associated with enhanced motivation to change their gaming behavior (r=0.488; P=.01), as measured by the scores on the readiness to change the questionnaire.

A 3-way ANOVA of the quantified scores on the extent of the effect of the risk-benefit assessment revealed a significant main effect of evaluation type ($F_{1,48}$=47.048; P<.001) and interaction between group and evaluation type ($F_{1,48}$= 23.445; P<.001), indicating that benefits had a stronger effect on participants than did risks, and the control group reported a stronger effect of benefits than risks (t_{25}=−7.245; P<.001).

Response of Stopping the Game After Each Time Point

A 3-way ANOVA on deciding to stop or continue the game at different time points revealed a significant main effect for group ($F_{1,48}$=73.646; P<.001), with the IGD group exhibiting a higher tendency to continue the game than the control group, and the main effect for time point ($F_{1,48}$=8.490; P=.001; Figure 4), indicating a higher tendency to stop the game after the risk/benefit assessment, than that at baseline (mean difference 0.205, SE 0.058; P=.003) and after anger expression (mean difference 0.165, SE 0.057; P=.02). A significant group and time point interaction was also noted ($F_{1,48}$=3.886; P=.03), which was caused by the higher tendency of the IGD group to stop the game after the risk/benefit assessment than at baseline (t_{23}=3.761; P=.001) and after anger expression (t_{23}=2.933; P=.007).

Degree of Understanding the Virtual Parents' Perspective

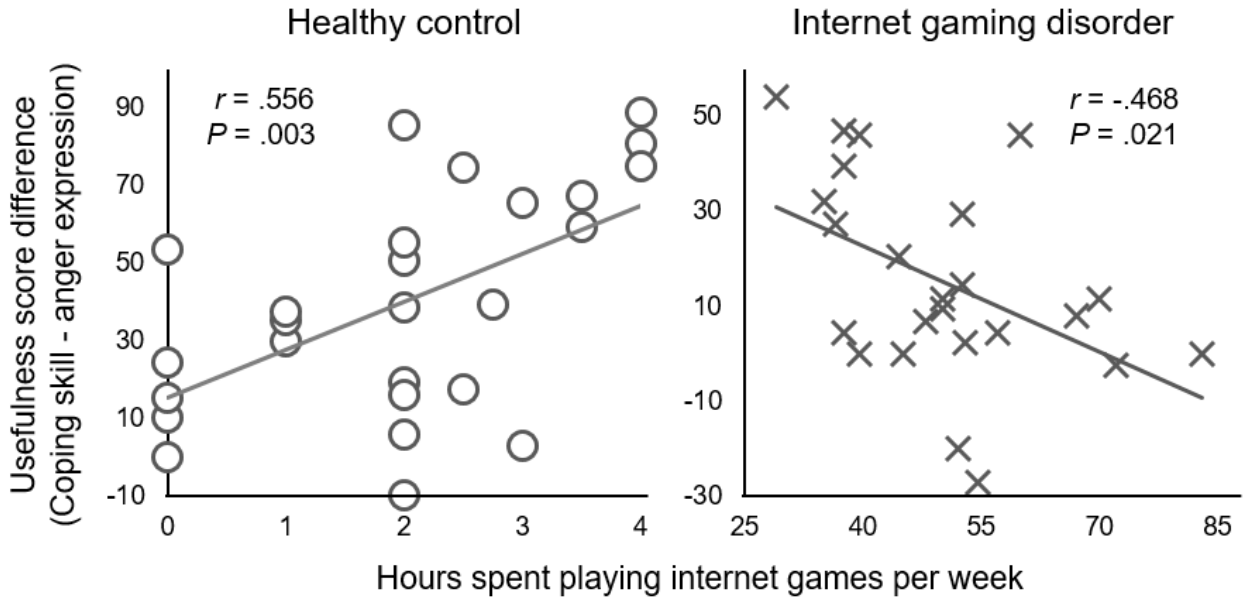
A 2-way ANOVA revealed a significant main effect for group ($F_{1,48}$=17.656; P<.001) and target ($F_{1,48}$=4.337; P=.04). In other words, the control participants exhibited a better understanding of their parents' perspective than those with IGD, and the participants had a better understanding of the virtual mother's perspective than that of the virtual father.

Usefulness of the Conflict-Resolution Strategy

A 3-way ANOVA on ratings for the usefulness of each strategy in resolving conflicts showed a significant main effect for group ($F_{1,48}$=5.328; P=.03) and strategy ($F_{1,48}$=52.667; P<.001); the control group evaluated the VR contents as more useful in resolving conflicts (Figure 4), and participants rated the coping skill as more useful in resolving conflicts than anger expression. There was a significant interaction between group and strategy ($F_{1,48}$=9.201; P=.004), indicating that the control group rated the coping skill as more useful than the IGD group (t_{48}=3.697; P=.001), but there was no significant difference in anger expression (t_{48}=0.372; P=.71).

As presented in Figure 5, in the control group, a higher number of gaming hours was associated with a higher tendency to perceive coping skills as more useful than anger expression (r=0.556; P=.003). In contrast, in the IGD group, fewer gaming hours were associated with a higher tendency to perceive coping skills as more useful than anger expression (r=−0.468; P=.02).

Figure 5. Correlations of mean gaming hours per week with a difference in the usefulness score of strategies.



Discussion

Principal Findings

In this study, we investigated the feasibility of a VR app for managing game-related conflicts with parents in young adults with IGD. The results showed that immersion in our VR program could provoke negative emotions (ie, anger) in individuals with IGD by placing them in interpersonal situations that would require them to manage these conflicts. Moreover, the clinical potential of our VR program was evidenced by the results of the (1) change in participants' gaming behavior within the program and (2) relationship between patients' usefulness rating for the implemented coping skills in resolving conflicts and the number of hours spent on gaming.

According to parents of adolescents with IGD, when they attempt to enforce time limits on the game, their children

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become angry, irrational, and even violent [12]. Thus, anger and violence seem to be common ways to manage such conflicts in families of individuals with IGD. In this context, our VR contents were developed to reproduce such anger-provoking situations in a hierarchical and interactive manner (eg, implementing staged manipulation to increase anger induction, matching the content of virtual parents' feedback to participants' anger expression type to simulate dyadic interactions, and allowing participants to express anger via a choice-based response format and verbal response) to increase the resemblance of our VR scenarios to reality. Data from the anger expression task showed that the intensity of the anger experience was higher in individuals with IGD than in control participants, suggesting that family conflict and its emotional response (ie, anger) can be simulated in VR scenarios. In line with this result, the perceived anger after the second expression was stronger than that after the first expression, indicating that the severity of the conflict increased. This experience may closely reflect the nature of conflict regarding time limits on games in families of youth with IGD. Therefore, the use of hierarchical and interactive scenarios for anger induction in VR apps could aid the closer-to-reality simulation of the progression of game-related arguments between family members.

In this study, the VR scenarios allowed participants to consider the benefits and risks of stopping the game immediately as a coping skill for managing family conflicts. The results showed that control participants reported more benefit items than risks. However, no difference was seen in the number of examples of risks and benefits expressed by participants in the IGD group. In line with this result, control participants reported that perceived benefits had a greater influence on them than perceived risks, whereas individuals with IGD did not assign more weight to the effect of benefits than risks. This perception could contribute to their continuous engagement in addictive behavior, as observed in other addictive disorders [25,27]. Hence, this study demonstrates the potential applicability of VR in treating IGD by helping participants to learn the use of risk/benefit assessment of stopping a game.

Our most important finding is that after engaging in assessing the risk/benefit of stopping gaming immediately during repeated exposure to parents' attempts to limit game time, the IGD group exhibited a higher tendency to choose to stop gaming. As one of the putative mechanisms of CBT to elicit adaptive behaviors is the acquisition of coping and problem-solving skills [38], the results of this study suggest that VR-CBT using risk/benefit assessment to stop gaming could potentially help individuals with IGD to exhibit more desirable behaviors and manage gaming-related family conflicts more effectively.

Taking another person's perspective is one of the important processes involved in social cognition [39]. Deficits in social cognition may increase social withdrawal and aggression, which might lead to a vicious cycle of substance use [40]. In addition, consistent with the role of empathy in addiction, a previous study reported an association between empathy and IGD symptoms [41]. Similarly, in this study, although participants had the opportunity to talk about the virtual parents' feelings or thoughts from their perspective, individuals with IGD exhibited a lower understanding of the perspective of the virtual parents compared with control participants. Thus, it can be inferred that impairment of the perspective-taking ability in individuals with IGD may hinder the resolution of game-related conflicts with significant others in real life, which, in turn, may lead them to continue gaming for excessive periods. Together, the findings of this study suggest that our VR content has the potential to be used as a medium for anger management by offering individuals with IGD opportunities to practice taking the perspective of significant others in real-life scenarios and to discuss their thoughts and feelings about difficulties in perspective-taking with clinicians.

After implementing each strategy to manage conflicts with the virtual parents, the participants were instructed to evaluate the overall usefulness of the conflict-resolution strategy employed. Overall, compared with control participants, individuals with IGD evaluated the 2 coping skills as less useful. Moreover, patients with longer gaming hours perceived coping skills as less useful than anger expression in resolving conflicts. This result suggests that IGD individuals with longer gaming hours may not feel the need to engage in more adaptive coping strategies to decrease their gaming hours. Moreover, the association between the usefulness rating of coping skill training in our VR and actual gaming hours indicates that VR parameters may reflect real-life gaming behavior of IGD youths or having a greater tendency to use adaptive coping skills are correlated with less severe symptoms of IGD measured by the gaming hours. Thus, the VR program may benefit young adults with IGD by aiding the assessment of IGD symptomatology. Moreover, given that adaptive coping acts as a buffer against psychological problems, a prior study suggested that a greater tendency to use coping skills such as risk/benefit assessment and perspective-taking of others could mitigate the development of more severe symptoms of IGD [42].

Limitations

This study has some limitations that warrant future research. The small sample size, sample composition of young Asian male adults, and relatively mild level of IGD severity among our participants limit the generalizability of our findings to the general population. In addition, 2 patients with mild depression were included; the presence of a comorbid condition may be a confounding factor for them. However, the main findings of our study generally remained the same as when excluding participants with comorbidities. Our VR contents still have to be tested in a larger, more heterogeneous sample before its potential role in IGD management can be discussed. Moreover, the present brief and time-limited application of our VR does not suggest that the behavior change achieved could also be applied to real-life situations. Furthermore, behavioral or questionnaire measures were not used to assess the empathic or perspective-taking ability of the participants. In addition, many feedback options were predesigned by the authors, such as the expressions of anger being read out by a male voice in our VR scenario. If participants had been able to verbalize their emotions in their own words, the results of our experiment might have differed. Prior studies have reported that *self-speech* is helpful for self-regulating cognition and behavior [43]. As computer technologies related to voice recognition and acoustic meaning-based speech analysis have developed, speech has also

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become a viable interaction modality in VR environments. Therefore, a scenario with a self-speech component should be designed to explore this issue in future studies.

In addition, the levels of symptom severity or other behavioral measures in the VR program were based only on subjective reports. Objective physiological markers, such as measurement of psychophysiological reactivity or reports from caregivers regarding participants' behavioral/emotional problems, would provide additional information. Finally, our preliminary study design did not allow for the validation of the ability of our program to reduce IGD symptoms or increase one's perspective-taking ability. To further validate the effects of this program, a follow-up study should include a control group comprising individuals with IGD who are not exposed to this VR app.

Conclusions

We developed a VR program that simulated gaming-related conflicts between young adults and parents and tested its effectiveness in managing problems between family members in an adaptive manner. Considering that the traditional therapeutic approach is dependent on in vivo (real-life) exposure or imagination capabilities of individuals, our VR program may offer an alternative for individuals with IGD to learn how a chronic cycle of conflicts is developed. In addition, it enabled them to access dysfunctional thoughts behind the conflicts (ie, perceived unreasonable risks of stopping a game and thoughts acting as a barrier to perspective-taking) easily and safely. Given that a number of risk and protective factors for young individuals with addiction could be influenced by the family context, our findings suggest the potential use of VR-based apps in the management of family conflicts experienced by individuals with IGD. A clinical trial using VR combined with CBT may shed more light on the effects of learning in VR over time.

Acknowledgments

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Content of participants' anger expression and virtual parents' feedback.
[DOCX File , 14 KB - games_v9i1e22494_app1.docx]

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Abbreviations

ANOVA: analysis of variance
CBT: cognitive behavioral therapy
IGD: internet gaming disorder
MET: motivational enhancement therapy
PQ: presence questionnaire
SSQ: simulator sickness questionnaire
VR: virtual reality

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Original Paper

Promoting Physical Activity in Japanese Older Adults Using a Social Pervasive Game: Randomized Controlled Trial

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Abstract

Background: Pervasive games aim to create more fun and engaging experiences by mixing elements from the real world into the game world. Because they intermingle with players' lives and naturally promote more casual gameplay, they could be a powerful strategy to stimulate physical activity among older adults. However, to use these games more effectively, it is necessary to understand how design elements of the game affect player behavior.

Objective: The aim of this study was to evaluate how the presence of a specific design element, namely social interaction, would affect levels of physical activity.

Methods: Participants were recruited offline and randomly assigned to control and intervention groups in a single-blind design. Over 4 weeks, two variations of the same pervasive game were compared: with social interaction (intervention group) and with no social interaction (control group). In both versions, players had to walk to physical locations and collect virtual cards, but the social interaction version allowed people to collaborate to obtain more cards. Changes in the weekly step counts were used to evaluate the effect on each group, and the number of places visited was used as an indicator of play activity.

Results: A total of 20 participants were recruited (no social interaction group, n=10; social interaction group, n=10); 18 participants remained active until the end of the study (no social interaction group, n=9; social interaction group, n=9). Step counts during the first week were used as the baseline level of physical activity (no social interaction group: mean 46,697.2, SE 7905.4; social interaction group: mean 45,967.3, SE 8260.7). For the subsequent weeks, changes to individual baseline values (absolute/proportional) for the no social interaction group were as follows: 1583.3 (SE 3108.3)/4.6% (SE 7.2%) (week 2), 591.5 (SE 2414.5)/2.4% (SE 4.7%) (week 3), and −1041.8 (SE 1992.7)/0.6% (SE 4.4%) (week 4). For the social interaction group, changes to individual baseline values were as follows: 11520.0 (SE 3941.5)/28.0% (SE 8.7%) (week 2), 9567.3 (SE 2631.5)/23.0% (SE 5.1%) (week 3), and 7648.7 (SE 3900.9)/13.9% (SE 8.0%) (week 4). The result of the analysis of the group effect was significant (absolute change: η^2=0.31, *P*=.04; proportional change: η^2=0.30, *P*=.03). Correlations between both absolute and proportional change and the play activity were significant (absolute change: *r*=0.59, 95% CI 0.32 to 0.77; proportional change: *r*=0.39, 95% CI 0.08 to 0.64).

Conclusions: The presence of social interaction design elements in pervasive games appears to have a positive effect on levels of physical activity.

Trial Registration: Japan Medical Association Clinical Trial Registration Number JMA-IIA00314; https://tinyurl.com/y5nh6ylr (Archived by WebCite at http://www.webcitation.org/761a6MVAy)

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KEYWORDS

aged; physical activity; pervasive games; social interaction

Introduction

The proportion of elderly people is increasing in populations worldwide as a natural consequence of the progression in health care and technology, as well as decreased birth rates [1]. This phenomenon intensifies the need for effective strategies to promote the well-being of elderly people. Previous work addressed that goal using different approaches, each with different levels of success [2]. Electronic games became a major topic of interest, being used in varied fields such as the rehabilitation of psychomotor functions [3,4], prevention of age-related diseases [5], and promotion of active lifestyles [6]. In that context, pervasive games are a relatively recent field of research [7].

A pervasive game is an electronic game that blends the real and virtual worlds, proposing interactions that incorporate elements from players' daily lives into the game rules [8]. They can be especially beneficial for elderly people for three main reasons. First, such games often invite players to walk to real-world locations [9] or to perform different exercises with their bodies [10], and both types of interaction promote higher levels of physical activity, a practice strongly correlated with well-being among the elderly [11-13]. Secondly, these games can encourage social connection, which is an important factor in the maintenance of both physical and mental health among senior citizens [14]. Finally, pervasive gaming experiences also focus on casual gameplay by nature, allowing players to learn on their own pace and giving them a lot of freedom to choose how much they want to engage with the game, an aspect of particular interest for elderly players [15].

In this work, we explore pervasive games for elderly individuals from a design perspective, focusing on a specific design aspect—social interaction—and targeting a specific goal, which is to promote physical activity. To do that, we used a previously developed pervasive mobile game [16-18] and performed a randomized controlled trial with Japanese elderly people, evaluating whether the presence of social interaction elements has any effect on levels of physical activity.

Methods

Design

A single-blind randomized controlled trial was conducted to compare two groups. In the intervention group, participants played a version of a pervasive game that included social interaction elements. In the control group, participants played a single-player version of the same game. A 4-week protocol was adopted. During the first week, participants did not play the game, but their level of physical activity was measured to serve as the baseline. During the remaining weeks, participants could freely play the game, while their levels of physical activity and game actions were monitored. Participants were blinded to group assignment, but researchers were not.

Participants

Participants were recruited from community-dwelling senior adults living in Kyoto City, Japan, using flyers. Because this research is contextualized as a preventive health intervention and it is expected that experience with games will become increasingly common among older adults in the future, we adopted a broader age range of 50 years and older into the study's inclusion criteria, aiming for middle-aged and older adults. Additional criteria included healthy people with independent ambulation and no cognitive or physical impairment that prevented them from understanding the instructions of the game or taking short walks.

All participants signed an informed consent term, and the research protocol was approved by the Kyoto University Hospital's Ethical Committee, which reports compliance with the Declaration of Helsinki. Participants were offered a shopping voucher worth 10,000 Japanese yen (US $96.51) as compensation for their participation in the study. The only requirement to receive the voucher was answering the final questionnaire at the end of the study.

Game

Participants played a pervasive location-based mobile game called Shinpo, which, in free translation, means "steps of the gods" in Japanese. This game was first evaluated for its feasibility in Kyoto [19] and later used in a similar study in Brasília, Brazil [20].

In Shinpo, players must collect virtual cards (Figure 1) by visiting shrines and temples in Kyoto city. Each card features an animal and a color, which indicates its level. There are four levels, and the goal of the game is to collect the card of highest level for all animals.

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Figure 1. Examples of virtual cards in Shinpo.



On the main screen of the game (Figure 2A), players could see a map showing their current location and nearby hotspots, which were indicated by red icons. Hotspots were defined using Google Maps information about shrines and temples in Kyoto City. After visualizing nearby hotspots, players had to walk physically toward them, and when they were within 50 m of their locations, a "check-in" option appeared, allowing the player to register a visit. For safety reasons, players were not expected to keep the game screen open while walking and should have accessed the game only when they arrived at a destination. If the game was open and the player's speed exceeded a certain threshold, the game warned the player not to walk while looking at the smartphone.

Figure 2. Examples of game screens. (A) Players used the map to search their neighborhood to find temples and shrines. (B) Players could visualize their cards and exchange 5 equal cards of a given level for 1 card of the next level. (C) Players could leave a copy of a card in a place they visited, and other players would see a mark in places where this was done. (D) Players were assigned to challenge groups and were notified when members of the group visited places, which added cards to all members of the group.



A player received a random level 1 card for every unique hotspot they visited within a day, or for every 1000 steps they walked. The step count was measured using a background service that operated whenever the smartphone was turned on. This software used Google Android's Sensor application programming interface, which is the same as that of Google Fit, an application previously shown to have an accuracy comparable to that of wearable devices [21]. At any moment, players could trade 5 equal cards of the same level for 1 card of the next level (Figure 2B).

In the version of the game with social interaction, additional rules were added to stimulate players to interact and collaborate to obtain more cards:

- Players could leave one copy of any of their cards, up to level 2, on each hotspot they visited each day, once in the morning and once in the afternoon (Figure 2C). If this happened, that hotspot would be highlighted on other players' devices, with an exclamation mark added to its icon. When a different player visited the highlighted hotspot, they received a copy of the card left there and the original visitor received additional random cards.
- Every day, players were randomly assigned to a challenge group, and anytime a person in the group collected a card, all other members also received a card. The members of the group and their contribution to the challenge were shown to all other members to promote a sense of unity (Figure 2D).
- All players could choose a public avatar and nickname and could make a short self-introduction; when players received cards as the result of other players' actions, they had a chance to give them a "like" (Figure 2D).

The feasibility study and follow-up evaluations [17,22] suggested that these mechanics allowed players to feel more engaged in playing the game by working together with other people. We hypothesized that this setup would result in a greater positive effect on levels of physical activity.

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Outcome Measures

The main observed outcome was the level of physical activity, measured by the average number of steps per week, in a 4-week period. During the first week, participants did not play the game, but their step count was still monitored. This monitoring was performed to assess their baseline level of physical activity. After that, they played the game for 3 weeks. Weekly cycles were chosen to consider different lifestyle behavior patterns during different days of the week. Also, to account for individual differences among participants, the proportional change in relation to the individual's baseline level of physical activity was also analyzed.

To evaluate how much participants played the game, the weekly average number of visits to hotspots was also observed. Within a single day, this observation represented the number of unique hotspots visited by the player, while within a week, it was the sum of the visits in each day of the week (ie, the same hotspot was not counted twice for the same day, but it could be counted twice in a week). This measurement was used because players were directed to not keep the game open while walking, so play time was not a good measurement of how much a person played.

As a secondary evaluation, participants were also asked to answer a final survey composed of the Game Experience Questionnaire (GEQ) [23] (including the "Social presence" section) and the System Usability Scale (SUS) [24], since these questionnaires have been widely used in previous works. The items of these questionnaires were translated and cross-verified by 2 Japanese native speakers. All items consisted of 5-point Likert scales. In the case of the GEQ, the scale was 0=didn't feel it at all to 4=felt it extremely; for the SUS, the scale was 0=don't agree at all to 4=completely agree. Besides these two metrics, participants were also asked to respond to the statement "I remembered to carry the smartphone with me when I left home" according to the following scale: 0=every day, 1=often, 2=sometimes, 3=almost never, and 4=never. Finally, at the end of the survey, participants could freely write comments, criticisms, or suggestions.

Procedures

At the beginning of the study, participants signed an informed consent form and completed the first questionnaire (ie, regarding their previous experience with games and technology). Their smartphones were checked for compatibility, and the game was then installed. Compatible systems included Android-based smartphones with Android operating system version 6.0 or above with a global positioning systems (GPS) sensor and an internet connection. Participants who did not have a compatible smartphone or who could not or did not want to use their personal devices were lent a previously prepared one by the researchers. Participants were given an instruction manual and an oral presentation about basic smartphone usage and the rules and interface of the game.

Participants were randomly assigned to either the social interaction group (intervention group) or no social interaction group (control group), and remained blind to their group assignment. During the first week, no participant could play the game, and the application only showed a message indicating that their step count was being monitored and providing the date on which the game would become available. From the second week on, the game became available and participants were able to play freely. There was a follow-up meeting on the same weekday every week, in which researchers were available to clarify any doubts or solve technical problems.

Participants were instructed about the importance of keeping their smartphones turned on and carrying them with them whenever they left their homes, throughout the duration of the study, since they would be used to measure the participants' step counts. In the final survey, they were also asked about their compliance with these instructions.

After the end of the trial, participants answered the final questionnaire to evaluate their experience while playing and received the voucher for 10,000 Japanese yen (US $96.51).

All questionnaires were administered by researchers, who were available to answer any questions about the items.

Data Analysis

Questionnaire data were consolidated to report percentages for each item, while means and standard errors were calculated for demographic data. Participants were considered active in a given day if they performed at least one check-in at a hotspot during that day. If a participant spent 3 or more days being inactive in a week, they were considered an inactive participant for that week. No participant explicitly asked to leave the study. Data were processed using Python (mainly the Pandas and Matplotlib packages) and exported into a suitable format for R, which was used for statistical analysis.

To analyze the effects, we calculated the change in the number of steps for each week from the baseline values in week 1. These measurements were made for each participant in relation to their own individual baseline value, and the proportional change was also calculated (ie, the absolute change divided by the baseline value). This was done to consider the effect on each participant in relation to their own initial baseline value.

In the statistical model, the change for each week after baseline was considered to be a repeated measure, and an analysis of variance (ANOVA) was performed—with group and week as factors—for participants who remained active until the end of the experiment. The relationship between the change in the step count and the number of hotspot visits was evaluated using Pearson's correlation coefficient (r).

For the final questionnaires, the value of negatively phrased items was inverted, and the mean and standard error was calculated for each category of the GEQ and for the SUS as a whole, resulting in scores that ranged from 0 to 4.

Results

Participants

A total of 20 participants (16 females, 4 males) were recruited, and 18 participants (14 females, 4 males) remained active until the end of the study. Table 1 presents basic information about the participants, including their previous experience with games and technology.

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Table 1. Basic data of study participants (N=20).

	Baseline		Active until the end	
Participant data	No social interaction	Social interaction	No social interaction	Social interaction
Demographics				
Participants, n	10	10	9	9
Sex (female), n (%)	9 (90)	9 (90)	7 (78)	7 (78)
Age (years), mean (SE)	66.4 (10.2)	63.2 (8.5)	64.6 (8.9)	62.2 (8.4)
PC[a] usage frequency, n (%)				
Never	3 (30)	2 (20)	3 (33)	2 (22)
Approximately 1 time/week	1 (10)	3 (30)	1 (11)	3 (33)
≥2 times/week	2 (20)	2 (20)	1 (11)	2 (22)
Daily	4 (40)	3 (30)	4 (44)	2 (22)
PC activity[b], n (%)				
Use email	7 (70)	5 (50)	6 (67)	4 (44)
Browse the web	4 (40)	6 (60)	4 (44)	5 (56)
Search the web	4 (40)	6 (60)	4 (44)	5 (56)
Read the news	5 (50)	5 (50)	4 (44)	4 (44)
Use social networks[c]	3 (30)	3 (30)	4 (44)	2 (22)
Manipulate photos	5 (50)	5 (50)	4 (44)	4 (44)
Use office applications	6 (60)	6 (60)	5 (56)	5 (56)
Mobile phone activity[b], n (%)				
Make calls	9 (90)	10 (100)	8 (89)	9 (100)
Use email	9 (90)	10 (100)	8 (89)	9 (100)
Browse the web	7 (70)	9 (90)	6 (67)	8 (89)
Use social networks	7 (70)	10 (100)	6 (67)	9 (100)
Install and use apps	7 (70)	10 (100)	6 (67)	9 (100)
Play frequency of nonelectronic games, n (%)				
Never	0 (0)	5 (50)	0 (0)	5 (50)
Very rarely	7 (70)	4 (40)	6 (60)	3 (30)
Approximately 1 time/week	2 (20)	0 (0)	2 (20)	0 (0)
≥2 times/week	1 (10)	1 (10)	1 (10)	1 (10)
Daily	0 (0)	0 (0)	0 (0)	0 (0)
Play frequency of electronic games, n (%)				
Never	1 (10)	3 (30)	1 (10)	3 (30)
Very rarely	6 (60)	2 (20)	5 (50)	2 (20)
Approximately 1 time/week	0 (0)	0 (0)	0 (0)	0 (0)
≥2 times/week	0 (0)	3 (30)	0 (0)	2 (20)
Daily	3 (30)	2 (20)	3 (30)	2 (10)
Devices used to play[b,d,e], n (%)				
PC	3 (33)	2 (29)	3 (38)	1 (17)
Portable console[f]	1 (11)	1 (14)	1 (13)	1 (17)
Conventional console[g]	0 (0)	0 (0)	0 (0)	0 (0)
Mobile phone or tablet	5 (56)	5 (71)	5 (63)	5 (83)

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Participant data	Baseline		Active until the end	
	No social interaction	Social interaction	No social interaction	Social interaction
Play partners[b,d,e], n (%)				
Young family members	1 (11)	0 (0)	1 (13)	0 (0)
Adult family members	0 (0)	0 (0)	0 (0)	0 (0)
Friends	1 (11)	0 (0)	1 (13)	0 (0)
Strangers online	1 (11)	0 (0)	1 (13)	0 (0)

[a]Personal computer.

[b]Participants could indicate more than one item.

[c]LINE, Facebook, Twitter, Instagram, etc.

[d]Some people reported playing but did not indicate an option for this item.

[e]Percentages are relative to the number of people who reported any play activity.

[f]Nintendo 3DS, PlayStation Portable, etc.

[g]Nintendo Switch, PlayStation, etc.

Participants in both groups had similar backgrounds of experience using a personal computer (PC), but there were some differences in other areas. For mobile phone usage, participants in the social interaction group had a higher level of self-reported skill, although both groups reported a high level. As for previous experience with games, more participants in the no social interaction group reported playing nonelectronic games than participants in the social interaction group, while the opposite was true for electronic games. Only participants in the no social interaction group reported ever playing games together with other people.

Participants could freely write down titles of games that they often played. For nonelectronic games, cited titles included the following (stated as number of citations by participants in the no social interaction group and in the social interaction group, respectively): crosswords (2 and 0), card games (1 and 1), sudoku (1 and 1), Go (1 and 1), puzzle games (1 and 0), Shogi (0 and 1), Reversi (0 and 1), and Concentration (0 and 1). For electronic games, cited titles included the following: Disney Tsum Tsum (1 and 4), Pokémon (1 and 0), Pokémon Let's GO (1 and 1), Pokémon GO (1 and 2), Animal Crossing (several versions) (2 and 1), Solitaire (1 and 1), Splatoon (0 and 1), Homescapes (1 and 0), the Legend of Zelda (1 and 0), Monster Hunter (1 and 0), puzzle games (1 and 0), Everybody's Golf (0 and 1), Mahjong (0 and 1), and LINE POP (0 and 1).

Except for 1 participant in the social interaction group, all participants used borrowed devices. Of the 20 total participants, 9 had an iPhone (Apple Inc) and could not install the application, while the remaining 10 participants that borrowed a mobile phone said that they did not want to install the application on their own device.

Main Outcome

Step count data are shown in Table 2 for participants who remained active until the end of the experiment. The baseline column shows the step counts recorded during the first week for each group. The remaining columns report the change for the subsequent weeks in relation to the participants' own baseline values. If $w_{p,i}$ is the number of steps on week "i" for participant p, and b_p is the baseline number of steps for that participant, then the absolute change is calculated as $\Delta_{p,i}=w_{p,i}-b_p$ and the proportional change is calculated as $q_{p,i}=\Delta_{p,i}/b_p$.

For the absolute change, the effect of group as a factor in the ANOVA was significant (P=.04; η^2=0.31). No relevant relationship was found with week as a factor (P=.19). For proportional change, using group as a factor resulted in a P value of .03 (η^2=0.30), while using week as a factor resulted in a P value of .17.

For number of hotspot visits, the no social interaction group had a mean of 42.8 (SE 15.8) visits in week 2, 89.7 (SE 24.5) visits in week 3, and 96.2 (SE 35.4) visits in week 4. By comparison, the social interaction group had a mean of 169.0 (SE 63.9) visits in week 2, 115.0 (SE 40.0) visits in week 3, and 140.0 (SE 57.6) visits in week 4.

The correlation analysis between the absolute change in the number of steps and the number of hotspot visits resulted in a correlation factor of r=0.59 (95% CI 0.32 to 0.77). When proportional change was considered, the correlation factor was r=0.39 (95% CI 0.08 to 0.64).

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Table 2. Number of steps at baseline for each group and individual variations in subsequent weeks.

		Median change (min; max)		
Group and change from baseline	Baseline, median (min; max)	Week 2	Week 3	Week 4
No social interaction group				
Absolute change[a]	42,305 (27,687; 71,028)	921 (–7986; 11,454)	437 (–7999; 8587)	–1143 (–6611; 6476)
Proportional change (%)[b]	NA[c]	4.8 (–16.0; 28.1)	1.8 (–11.3; 16.3)	–1.6 (–9.7; 18.7)
Social interaction group				
Absolute change	51,254 (20,356; 65,594)	10,494 (–508; 27,167)	5954 (4944; 20,711)	3722 (–2691; 22,891)
Proportional change (%)	NA	24.4 (–1.0; 54.5)	24.2 (7.6; 41.5)	10.0 (–12.2; 45.9)

[a]Absolute values indicate the change in the weekly number of steps when compared with the user's own baseline value.

[b]Proportional values indicate the absolute value divided by the user's own baseline value (ie, if $\Delta_{p,i}$ is the change from baseline to week "i" for participant p, and b_p is the baseline number of steps for that participant, then the proportional change $q_{p,i}=\Delta_{p,i}/b_p$.

[c]NA: not applicable.

Game Experience

The scores for the usability and game experience questionnaires are summarized in Table 3. The scores of component items ranged from 0 to 4; therefore, a value of 2 or greater indicates a high valuation. The data included are only those from participants who stayed active until the end of the experiment. Since these data were used only as complementary information for future interventions, no further statistical analysis was performed.

For the statement "I remembered to carry the smartphone with me when I left home," 8 participants in the no social interaction group responded "everyday," and 1 participant in that group responded "often." In the social interaction group, all participants responded "everyday."

Participants' comments about the game were summarized by one of the researchers who is a native Japanese speaker and briefly interacted with the participants at the last meeting, in which they completed the final questionnaire. Comments made during the last meeting and also written on the questionnaires included the following: "The accuracy of the GPS could be improved," "I enjoyed visiting new places," "I want to continue playing," "I want Shinpo to notify me when I am near the temple," "It is difficult to understand the communication function," "I think it would have been more interesting if I was used to using smartphones," and, "There were too many notifications."

Table 3. Mean scores for Game Experience Questionnaire (GEQ) and System Usability Scale (N=18).

	Mean score (SE)[a]	
Category	No social interaction group (n=9)	Social interaction group (n=9)
GEQ: Core		
Competence	1.6 (0.3)	2.1 (0.3)
Sensory and imaginative immersion	1.7 (0.4)	2.3 (0.3)
Flow	1.4 (0.4)	1.6 (0.3)
Tension	0.5 (0.2)	1.1 (0.3)
Challenge	1.3 (0.3)	1.5 (0.3)
Negative affect	0.7 (0.3)	1.0 (0.2)
Positive affect	2.6 (0.4)	3.0 (0.3)
GEQ: Social presence		
Psychological involvement: empathy	0.8 (0.2)	2.0 (0.4)
Psychological involvement: negative feelings	0.5 (0.2)	1.0 (0.3)
Behavioral involvement	0.5 (0.3)	1.5 (0.5)
System Usability Scale	2.6 (0.2)	2.8 (0.1)

[a]Scores are normalized in the 0 to 4 interval; values equal or greater than 2 indicate a high score for the item.

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Discussion

Principal Results

Due to the limited number of participants, there were a few differences between the groups after randomization; however, both groups had similar previous experience with games and technology, and the proportions remained similar when only participants who remained active until the end were considered. For PC usage, most participants had at least some experience, and for smartphones, all participants knew at least the basic operations. Unsurprisingly, when previous experience with games was considered, most participants in both groups reported never playing games or playing them very rarely. Participants in both groups reported using PCs, handheld consoles, and smartphones to play, and no participant reported using a traditional gaming console. Most people reported playing alone, with only a few people in the no social interaction group and no one from the social interaction group reporting playing with other people.

For the main outcome, a greater positive effect was observed in the social interaction group than in the no social interaction group. The statistical analysis with respect to the absolute change indicated a large effect size (η^2=0.31), and P=.04 indicates a statistically significant difference. For proportional change, similar results were observed, with P=.03 (η^2=0.30). The correlation between the number of hotspot visits and the effect was also statistically significant, with a positive value in both cases (absolute change: r=0.59, 95% CI 0.32 to 0.77; proportional change: r=0.39, 95% CI 0.08 to 0.64), which suggests that the gameplay was one of the main factors that generated the effect. These results lead us to believe that the social interaction elements had a relevant positive effect on the levels of physical activity of the players.

The evaluations of game experience and system usability were used as complementary information only, and statistical analysis was not performed. The mean scores were higher for all items in the social interaction group. This suggests that this version of the game had a greater effect on players in "positive" aspects, such as "competence" and "sensory and imaginative immersion," but also in "negative" ones, such as "tension" and "psychological involvement—negative feelings." A possible explanation is that this version of the game provided a more intense experience in general. Nonetheless, if we consider as "positive" the categories of "competence," "sensory and imaginative immersion," "flow," "positive affect," "psychological involvement—empathy," and "behavioral involvement," the social interaction version was highly evaluated in 4 of them, and in none of the "neutral" or "negative" categories. For usability, both versions were highly evaluated.

Limitations

The limitations of this study are as follows. The main outcome was measured using smartphone software. The methodology has been evaluated in previous studies, and the authors of those studies concluded that it is adequate; however, the comparative studies considered indoor environments, and outdoor measurements may render different results. In addition, there might be differences in accuracy for different age groups. In this study, we considered weekly cycles and also analyzed the proportional values to evaluate the effects for each individual participant.

Future interventions might test similar settings with a different device, such as an external pedometer, and compare the results. In both cases, because the data are collected not in a controlled environment but rather in a user-dependent context and participants' adherence to carrying the device is self-reported, there might be inaccuracies in the measurements. We specifically instructed participants about the importance of carrying the smartphones with them so that their step counts could be measured; with the exception of 1 participant who responded "often" to the statement "I remembered to carry the smartphone with me when I left home," all other participants reported following this guideline every day. Nonetheless, future interventions might use more objective ways of measuring compliance.

Step counts were observed in a continuous state, considering any daily activity of participants, and the number of visits to hotspots was used as a proxy measurement of the amount of game play, since participants were encouraged to only open the game to check in at hotspots and close it between visits. Because step counts for the baseline week were also measured continuously and the analysis considered the observed change, the results are still relevant. Nonetheless, further interventions might also separate in-game counts explicitly and analyze if there is any difference.

The sample population was mostly composed of women, due in part to the fact that the majority of the Japanese elderly population is female, but mainly because of recruitment difficulties caused by the cultural context, such as the fact that most elderly people in Japan engage primarily in activities in gender-specific groups. A more gender-balanced sample would better represent the actual adult elderly population.

Although this study is included in the more general field of interventions to improve the quality of life of older adults, it focused specifically on increasing physical activity based on previous results that show a strong correlation between these variables. Future interventions could measure these two variables explicitly and evaluate their relationship in the context of pervasive games. Also, the questionnaires used to assess usability and game experience were not statistically validated, and were used only to provide complementary information rather than to draw conclusions about the effect. The use of validated metrics would allow us to further understand the data and test more hypotheses.

The proposed social interaction mechanics focused mainly on collaboration and virtual interaction. More types of social interaction and different variables can be tested, such as competition, direct (in-person) interaction, group dynamics, and interaction with family and friends, among others.

The final purpose of promoting physical activity is to increase the well-being of the elderly population. In this study, we evaluated specifically whether social elements in pervasive

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games would have any effect on the level of physical activity, but to evaluate the effect on well-being in general would require many additional metrics and a much longer period of time.

Comparison With Prior Work

This work is a follow-up of a similar study in Brazil [20], which was performed with a version of the game that was adapted to Brazilian culture but was otherwise identical. The results found in this evaluation were stronger than the results in the Brazil study, with similar values for proportional effects (the absolute effect was also larger, but the baselines were very different) and larger effect sizes for both absolute (η^2=0.30 versus η^2=0.19) and proportional (η^2=0.31 versus η^2=0.27) measurements. Additionally, while the Brazil study was inconclusive for the correlation between hotspot visits and proportional effect, the results in this study were statistically significant in all cases.

A few studies have already employed pervasive games or gamified apps targeting older adults, usually focusing on specific goals, such as cognitive training [25] and the promotion of physical activity using social incentives [26,27]. A successful commercial example that does not target elderly adults in particular but that became extremely popular among people of all ages is Pokémon GO [28]. Different studies have analyzed its effects on levels of physical activity, finding overall positive results, especially in the first weeks of use [29-31].

Recently, new research has emerged [32,33] analyzing in greater depth the experience of elderly people in play, based on the principle that games—even serious games—should primarily be fun because health benefits come later as a natural consequence of play [34]. In that respect, a few studies have attempted to clarify elderly players' needs and motivations and investigated possible challenges in designing games for older audiences, listing common physical and cognitive limitations that should be taken into consideration [35-39]. Other studies have attempted to identify the preferences of elderly people regarding the content and/or genre of the games [15,40-42]. In this study, we evaluated social interaction as a design element in the context of pervasive games, a new kind of game that is only now being explored. This study was limited and focused on a specific metric, namely physical activity, which was taken as a proxy, but the results suggest that this topic should be further investigated, with the consideration of additional variables related to the game experience.

Conclusions

In this work, we investigated whether the new genre of pervasive games could be used to increase physical activity among older adults by focusing on a specific design element, namely social interaction. Our results indicated that a pervasive game using social interaction had a greater positive effect on levels of physical activity than the same game without social interaction. This study had limitations, but the results are promising, and corroborated a previous study using the same game. In future interventions, other types of social interaction and/or design elements could be evaluated, and additional variables might be considered, such as indicators of physical and psychological health, among others.

Acknowledgments

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Conflicts of Interest

None declared.

Multimedia Appendix 1
CONSORT-eHEALTH checklist (V 1.6.1).
[PDF File (Adobe PDF File), 1000 KB - games_v9i1e16458_app1.pdf]

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Abbreviations

ANOVA: analysis of variance
GEQ: Game Experience Questionnaire
GPS: global positioning systems
PC: personal computer
SUS: System Usability Scale

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Original Paper

A Co-Designed Active Video Game for Physical Activity Promotion in People With Chronic Obstructive Pulmonary Disease: Pilot Trial

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Abstract

Background: People with chronic obstructive pulmonary disease (COPD) who are less active have lower quality of life, greater risk of exacerbations, and greater mortality than those who are more active. The effectiveness of physical activity interventions may facilitate the addition of game elements to improve engagement. The use of a co-design approach with people with COPD and clinicians as co-designers may also improve the effectiveness of the intervention.

Objective: The primary aim of this study is to evaluate the feasibility of a co-designed mobile game by examining the usage of the game, subjective measures of game engagement, and adherence to wearing activity trackers. The secondary aim of this study is to estimate the effect of the game on daily steps and daily moderate-to-vigorous physical activity (MVPA).

Methods: Participants with COPD who were taking part in the co-design of the active video game (n=9) acted as the experiment group, spending 3 weeks testing the game they helped to develop. Daily steps and MVPA were compared with a control group (n=9) of participants who did not co-design or test the game.

Results: Most participants (8/9, 89%) engaged with the game after downloading it. Participants used the game to record physical activity on 58.6% (82/141) of the days the game was available. The highest scores on the Intrinsic Motivation Inventory were seen for the value and usefulness subscale, with a mean of 6.38 (SD 0.6). Adherence to wearing Fitbit was high, with participants in both groups recording steps on >80% of days. Usage of the game was positively correlated with changes in daily steps but not with MVPA.

Conclusions: The co-designed mobile app shows promise as an intervention and should be evaluated in a larger-scale trial in this population.

(JMIR Serious Games 2021;9(1):e23069) doi:10.2196/23069

KEYWORDS

fitness trackers; chronic obstructive pulmonary disease; physical activity; video games; smartphone; mobile phone

Introduction

Background

Chronic obstructive pulmonary disease (COPD) is a leading cause of death worldwide [1] and is associated with persistent respiratory symptoms, reduced exercise capacity, and poorer quality of life [2,3]. People with COPD are generally less active than people without COPD [4,5], and physical activity levels generally decline as the disease progresses [6].

Inactivity in people with COPD is associated with poorer health-related outcomes, including a lower quality of life, greater risk of exacerbations, and greater mortality [6-10]. International guidelines promote regular physical activity in people with

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COPD, generally targeting 30 min of moderate physical activity on most days [11].

Interventions that are effective in achieving this targeted level of physical activity in people with COPD are limited [12,13]. Pulmonary rehabilitation, involving supervised exercise training, is strongly recommended for people with COPD [14,15], as it is very effective at increasing exercise capacity [16,17]. Despite this, many people with COPD struggle to maintain their physical activity levels in the months after pulmonary rehabilitation [18], and some do not become more active at all [19]. A longer period of pulmonary rehabilitation may be more effective at improving activity levels, with one systematic review finding that all studies showing no impact of exercise training on physical activity had durations of less than 12 weeks, whereas all interventions lasting longer than 12 weeks improved physical activity levels [12]. However, lengthening the duration of pulmonary rehabilitation beyond the 12 weeks may lead to reduced availability of places in pulmonary rehabilitation programs, which are already limited in many countries [20].

Consumer-grade electronic pedometers, such as those developed by Fitbit (Fitbit Inc), have been shown to be valid devices for measuring physical activity in people with COPD [21] and may enable people with COPD to be more conscious of their physical activity levels. Behavioral interventions that use technology such as wearable pedometers to facilitate self-monitoring of physical activity have shown some short-term effectiveness in improving physical activity levels in people with COPD [22,23]. However, the benefits of physical activity may be short lived, possibly because of poor long-term engagement with these interventions [24]. A recent Cochrane review of technology-based COPD self-management interventions concluded that “researchers also must take into consideration strategies that will promote long-term engagement with smart technology” [22].

Gamification is an emerging strategy to improve engagement with digital technology, including within the context of health care [25]. Gamification is the use of game design elements in nongame contexts [26] and is a common feature in health and fitness apps, including fitness tracker apps [27,28]. Most commonly, the apps include game features such as digital rewards for goal attainment, avatars (visual representations of players), social or peer pressure (including leaderboards), and the provision of feedback on performance. However, little research exists on game interventions paired with wearable activity trackers in people with COPD, and trials of gamified interventions in other populations have shown conflicting results. For example, a trial in healthy adolescents of an activity tracking website known as *Zamzee* (Zamzee Co) demonstrated a 54% increase in moderate-to-vigorous physical activity (MVPA) over 6 weeks [29], but a trial *Active Team (Portal Australia)*, a gamified smartphone app for healthy adults, had no effect on objectively measured MVPA over 3 months [30]. Although both interventions in these studies were gamified, they differed substantially in the game elements that were used [29,31], underscoring the impact that different designs can have on the effectiveness of gamification.

Active video games (AVGs), defined as video games that require physical activity to play [32], are another approach that has been used in an attempt to increase physical activity. A number of studies have investigated the use of AVGs in COPD and other chronic respiratory conditions, showing that they can evoke a similar physiological response to more traditional exercises (eg, stationary bicycle) while being more enjoyable [33]. However, the effect that AVGs have on habitual physical activity in an unsupervised setting has not been extensively studied in respiratory disease populations [34] or older adults [35]. In addition, the studies to date have generally used commercially available AVGs that are designed for the general population rather than for older adults [36] or to address the preferences of people with chronic diseases. Trials of AVGs in older adults with chronic diseases, such as COPD, are required, and such trials might be expected to demonstrate greater adherence or effectiveness if those AVGs are designed to take into account the needs and preferences of the patient population involved in the trial.

Aims

Using a co-design process with people with COPD and clinicians, we developed an AVG called *Grow Stronger* to promote physical activity in people with COPD after pulmonary rehabilitation. A co-design methodology known as participatory design was used. Participatory design is a research and design practice where the users of a particular system participate as co-designers throughout the design process rather than merely as testers providing feedback to designers [37]. A participatory design process can, at least in some circumstances, improve the effectiveness of serious games for health [38].

The primary aim of this study is to evaluate the feasibility of the *Grow Stronger* AVG intervention in people with COPD by assessing the usage of and engagement with the AVG, along with adherence to wearing the Fitbit activity tracker. The secondary aim of this study is to assess the effect of the Grow Stronger AVG, when combined with a Fitbit activity tracker and Fitbit app, on physical activity in comparison to the Fitbit activity tracker and Fitbit app alone. Primary outcomes included usage of the AVG in the experiment arm of this pilot trial (how often the AVG was used, what types and difficulties of activity goals were chosen, and what breathlessness values were reported), subjective measures of engagement with the AVG in the experiment group, and adherence to wearing Fitbit activity trackers in both the experiment and control arms. Secondary outcomes were daily steps and daily physical activity levels in both the experiment group and control group, as assessed by the Fitbit activity monitor.

Methods

Overview

This study is a pilot trial nested within an iterative co-design process to develop an AVG. This co-design process comprised a series of focus groups with people with COPD (n=10) and clinicians (n=18), aiming to outline, design, and develop an AVG. For the trial, 9 of the 10 people with COPD who were taking part in the co-design process comprised the experiment group, who received the AVG app in addition to a Fitbit activity

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tracker and Fitbit app. The control group comprised individuals with COPD who did not take part in the co-design process, who received only the Fitbit activity tracker and the Fitbit app.

The study was approved by the Prince Charles Hospital Human Research Ethics Committee and ratified by the University of Queensland Human Ethics Research Office.

The co-design process took place between June 2019 and November 2019, with the pilot trial being conducted for 3 weeks at the end of this process, from October 4, 2019 to October 25, 2019.

Participants

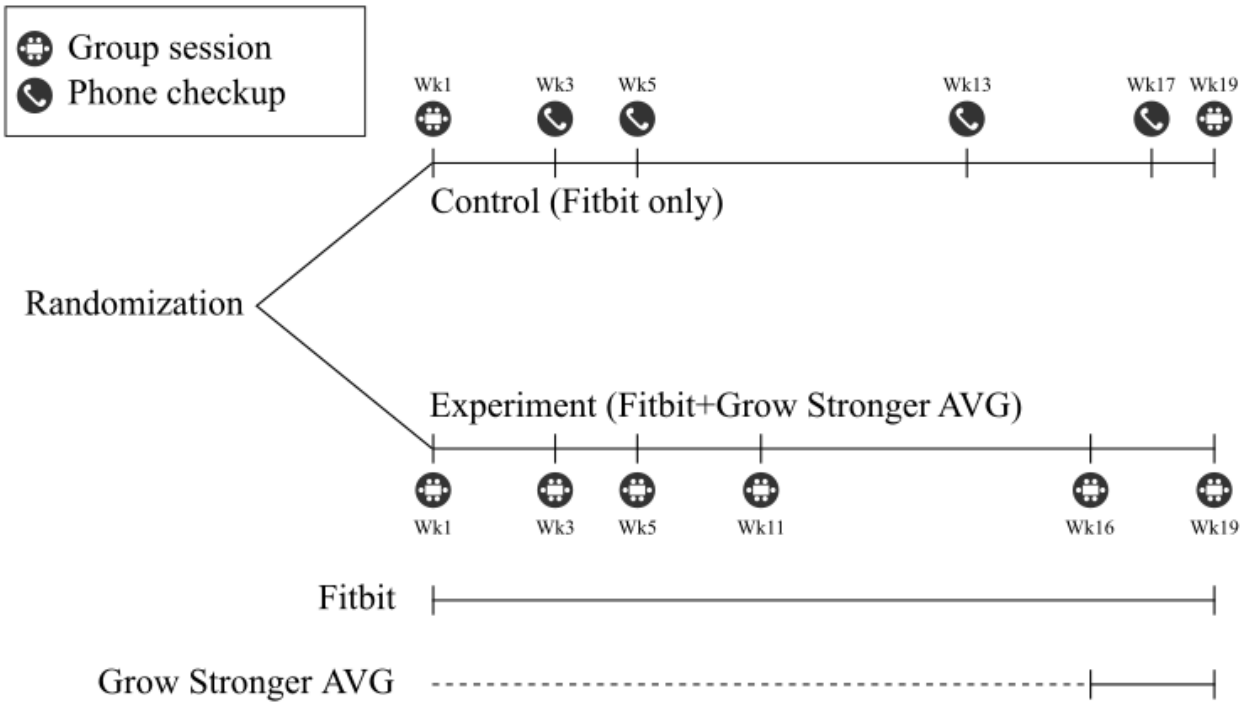
People who reported they had been clinically diagnosed with COPD were recruited. A letter containing information about the study was sent to recent (previous 12 months) attendees of pulmonary rehabilitation programs across 4 sites operated by Queensland Health in the Moreton Bay Region of Queensland, Australia. Interested potential participants were screened to ensure they met the inclusion and exclusion criteria. Participants were included if they had attended pulmonary rehabilitation in the past 12 months, were able to read and speak English, and were able to exercise independently (with or without the use of mobility aids and supplemental oxygen). Participants were excluded if they did not have access to a smartphone, were unable to exercise because of medical or physical limitations, required 24-hour supplemental oxygen, or lacked the visual acuity to view the text displayed on typical mobile devices.

Procedures

After all participants were recruited, a randomized sequence of participants was generated. Participants were alternately allocated into 2 groups: (1) an active co-design group (hereafter the experiment group), which took part in the focus groups and received an activity monitor and the AVG intervention and (2) a control group, which received an activity monitor but did not take part in focus groups or received access to the AVG. For the 19-week duration of the co-design process, participants in both the experiment and control groups were provided with a consumer-grade wearable activity monitor, namely, a Fitbit Alta HR or Fitbit Charge HR 2 (Fitbit Inc.). This activity monitor was paired to the participant's smartphone and was capable of tracking steps, physical activity, and heart rate. Participants in both groups were provided with instructions on how to use the Fitbit app, and participants in both groups were set up as friends with other participants within their group, allowing participants to see the weekly step total of other participants and access other social features. It was not possible to blind the participants to their group allocation.

The control group did not participate in the focus groups and only had in-person contact with the research team during a group enrollment session and study conclusion session. As per Figure 1, the control group received regular telephone check-ins across the trial duration to set appropriate step goals on the Fitbit app and to provide the same opportunity to raise any device-related issues as was afforded the experiment group before and after the focus groups. Participants in the experiment group were able to trial the test version of the AVG during the final 3 weeks of the development process. However, not all participants were able to download and use the app the day it became available, resulting in some participants having a shorter period to experience the AVG than others. At the conclusion of the trial, participants relinquished their wearable fitness trackers, but those using the app continued to have access to it for at least a month after the conclusion of the trial.

Figure 1. Contact times, types of contact, and interventions received for each group. Group sessions for the experiment group comprised focus groups in the co-design process along with an install session in week 16, whereas the 2 group sessions for the control group were a group enrolment session in the first week and a study conclusion session in the final week. AVG: active video game.



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Game Intervention

The *Grow Stronger* game and the co-design process undertaken to develop it will be described more fully elsewhere. In brief, *Grow Stronger* is a smartphone app that functions as both a game and a physical activity diary. Progress in the game requires the player to report the completion of upper body and lower body physical activities commonly used in the physical rehabilitation of people with COPD. The game features a simple stick figure image of each activity, and players are provided with an additional handout with more complete instructions for each activity. Each day, players choose an upper body and lower body activity and set at what difficulty or intensity they wish to perform these activities. At the completion of each activity, users must report their perceived Borg breathlessness value using a slider present in the app to receive their reward for that activity.

The game features 2 parallel game modes, which can be used together or separately. The first mode functions as a single player mode and uses the theme of growing a garden, where players are rewarded with water in a watering can that can be used to grow a potted plant. The second game mode functions as a cooperative multiplayer game mode and has the theme of a caravan trip around Australia, visiting multiple well-known Australian destinations. As a team, players are rewarded with progress on the trip, determined by the average number of activities completed by the team. All data from the use of the game are reported to a web interface that allows clinicians to monitor the progress of all players and sends encouraging messages. A more complete description of the game, along with representative screenshots and a full list of all available activities, is available in Multimedia Appendix 1.

Outcome Measures

Several primary outcome measures were collected by the AVG in the experiment group, namely, the usage of the app, type of activities completed, difficulty level selected by participants for each activity, and reported Borg breathlessness ratings for each physical activity. Adherence to wearing the Fitbit activity tracker was assessed using step data collected from the Fitbit devices, with nonwear defined as zero steps recorded for an entire day.

Additional primary outcome measures of subjective game engagement were collected at the conclusion of the study by asking the experiment group to complete 3 questionnaires. First, the Game Engagement Questionnaire (GEQ) was used [39], which was measured on a three-level scale (1=no, 2=maybe or sort of, 3=yes). Second, 5 subscales of the intrinsic motivation inventory (IMI) were employed: interest or enjoyment, perceived competence, effort or importance, value or usefulness, and relatedness [40]. Each of these subscales was measured on a seven-point Likert scale (1=completely disagree to 7=completely agree). Finally, a cognitive processing and cognitive activation (CPCA) questionnaire was developed for use in this study, adapted from Hollebeek et al [41] and measured on a 7-point Likert scale as for the IMI. All questions were given using either paper-based or web-based forms immediately after the final focus group.

Secondary outcome measures collected from all participants included total steps and duration and the intensity of physical activity. These measures were automatically collected for the entire 19-week duration of the study by the Fitbit activity trackers provided to participants in both the experiment group and the control group. Devices such as these are considered to be valid low-cost devices to measure physical activity in people with COPD [21]. MVPA was assumed to be the sum of the 2 highest Fitbit categories for active minutes (*fairly active* and *very active* categories). This approach has been previously used when comparing consumer-level activity monitors to research-grade accelerometers, demonstrating moderate-to-strong validity for MVPA measured by Fitbit devices in healthy adults in free-living conditions [42].

Before the first focus group, participants also filled in a prestudy survey, providing information on their gender, age, employment status, confidence in technology (on a 0-10 scale), and degree of self-perceived functional limitation because of breathlessness, as assessed using the Medical Research Council (MRC) dyspnea scale [43].

Data Analysis

Data were analyzed and visualized using Python (Python 3.7; Python Software Foundation). Step counts and minutes of activity were collated to a daily figure for each participant, which was used to compute each participant's average for steps per day and MVPA per day over the period before and after the AVG was downloaded. Days where no step data were recorded were ignored when calculating each participant's average steps per day and MVPA per day, effectively interpolating these missing days with the participant's own average for that period. One participant in the control group did not wear the Fitbit during the final 3 weeks of the study and so was excluded from the pre-post comparisons of steps per day and MVPA per day.

Owing to the small sample size and nonnormality evident in some outcomes, the Spearman rank correlations were used to examine relationships between outcome measures (ie, pre-post change in daily steps, change in MVPA, game engagement on GEQ and IMI scales, and game usage). The Spearman rank correlation is not affected by skewness and generally copes better with light-tailed distributions than the Pearson correlation [44].

As this was a pilot randomized controlled trial, with a sample size determined by optimum focus group size during the co-design process rather than being adequately powered to detect differences in primary outcome measures, no statistical tests were performed, and data are presented as mean and SD only.

Results

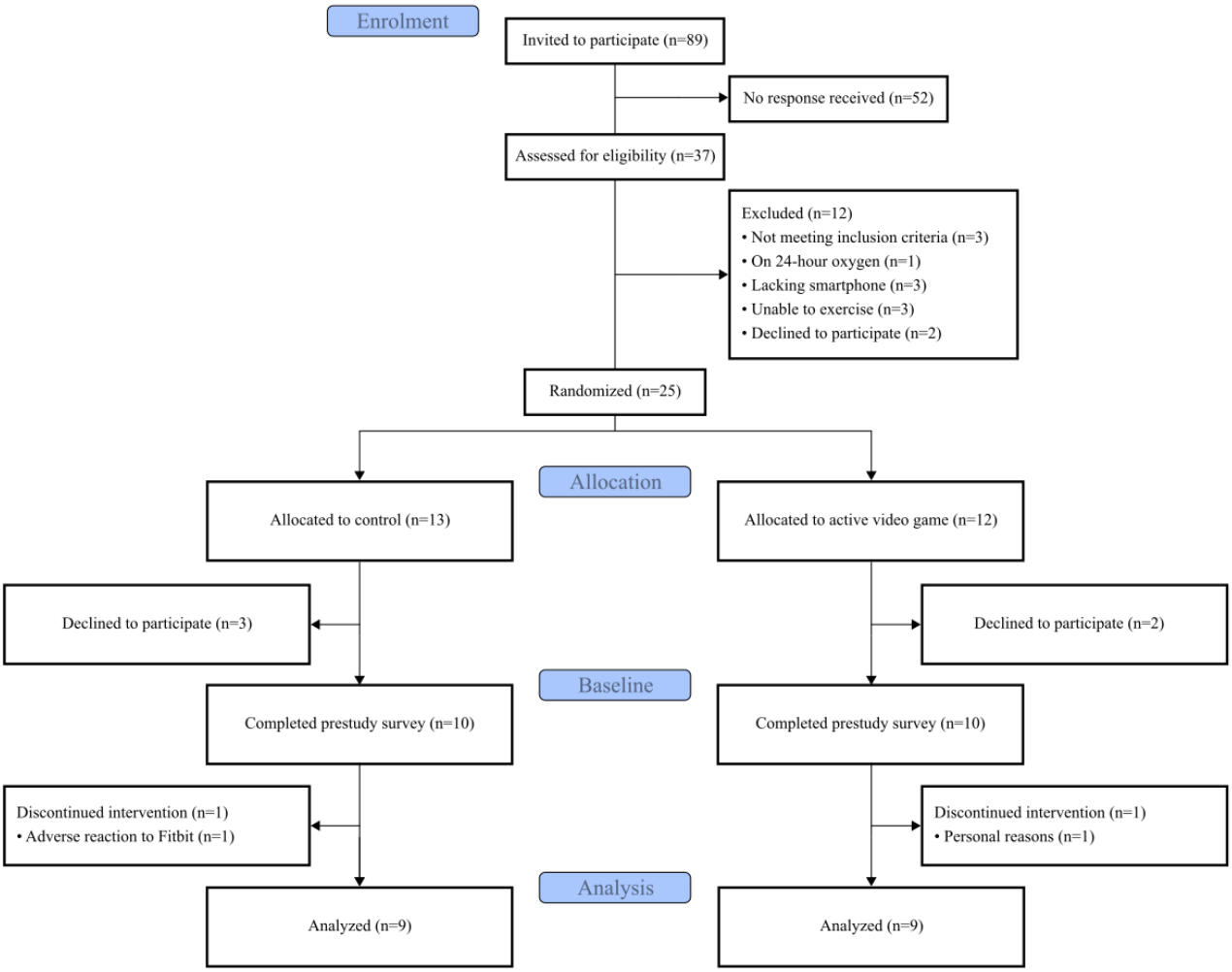
Participants

Figure 2 shows the progression of participants throughout the study in a Consolidated Standards of Reporting Trials diagram. Of the 89 participants invited to participate in the study, 37 responded and were screened against the inclusion and exclusion criteria. The 25 eligible and consented to participate were randomized into the 2 arms of the study. Of these, 10 from each group attended the first session and completed the prestudy

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survey. Overall, 2 participants discontinued and withdrew from the study, both during week 4. One participant withdrew for personal reasons, whereas the other withdrew because of reported skin irritation from the Fitbit device. Two other participants reported some skin irritation, resulting in low Fitbit adherence, but did not withdraw from the trial.

Figure 2. Consolidated Standards of Reporting Trials diagram showing the flow of participants through the study.



One Fitbit device had to be replaced during the trial because of issues with synchronization between the activity tracker and phone, but data were not lost. A number of participants also experienced issues with Bluetooth synchronization, but these issues were resolved after troubleshooting discussions with the research team, and this did not appear to result in a loss of data for any full day for any participant (although loss of part of the data for that day may have occurred).

The results from the prestudy survey for the control and experiment groups are shown in Table 1. Aside from the gender balance, there were no obvious differences between the groups. Both groups had an MRC dyspnea score between grade 2 and grade 3, indicating moderate functional limitation because of breathlessness.

Table 1. Details of participants who received the full intervention in each arm of the study (n=9).

Group	Control	Experiment
Female, n (%)	6 (67)	5 (56)
Age (years), mean (SD)	65 (7)	70 (6)
Retired, n (%)	8 (89)	9 (100)
Confidence with technology (0-10 scale), mean (SD)	5.2 (2)	5.3 (2.3)
Medical Research Council dyspnea, mean (SD)	2.4 (1.1)	2.4 (1.2)

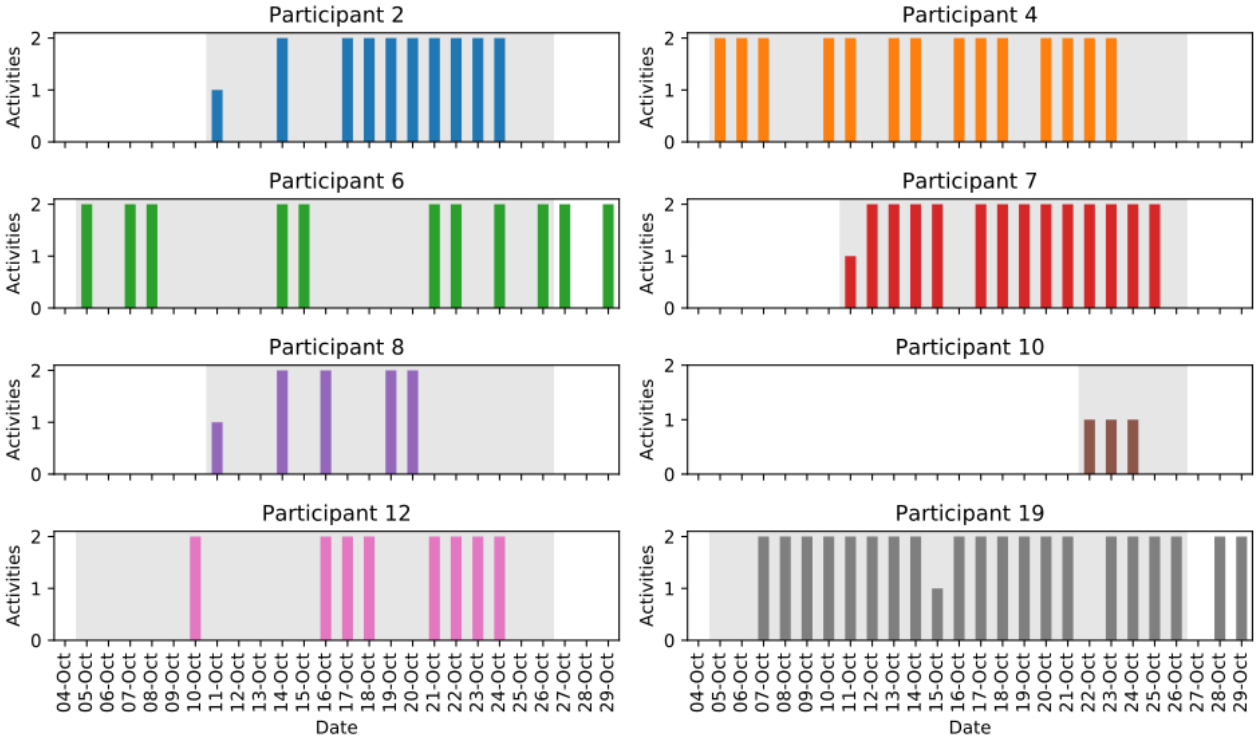
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Game Usage Statistics

Game Usage Frequency

The number of activities logged per day by each participant in the experiment group is shown in Figure 3. The game allowed a maximum of 2 activities to be recorded each day. Most participants (8/9, 89%) engaged in the game after downloading it. Excluding participants who did not use the game at all, the remaining participants logged at least one activity on 58.6% (82/141; SD 21%) of the days when they had access to the game during the test period. Note that not all participants downloaded and installed the game on their smartphone on the same date. Although the test period concluded on October 25, some participants continued to use the game after this date.

Figure 3. Number of activities recorded per day for each participant in the experiment group. The period where each participant had downloaded the game, but before the test period had concluded, is indicated by the shaded background. One participant was not shown, as they did not use the game after downloading it on their phone.

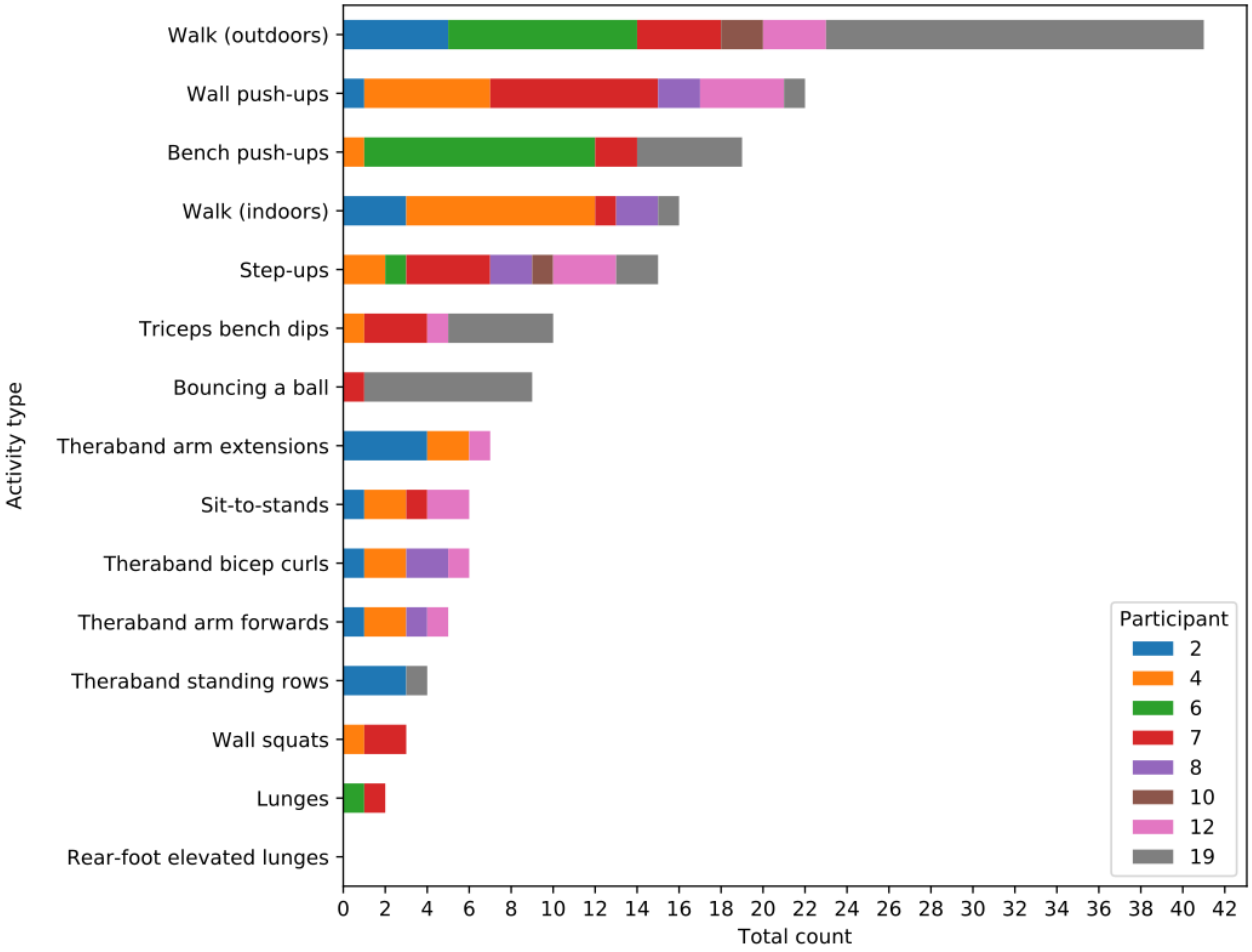


Types of Activities Recorded

Figure 4 shows the frequency of activities that were recorded using the app as well as which participants recorded which activity. Outdoor walking was by far the most recorded activity, recorded 41 times. Walking either indoors or outdoors represented 34.5% (57/165) of all recorded activities.

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Figure 4. Number of times each activity was recorded by participants in the experiment group.



Borg Breathlessness Values

The frequencies of Borg breathlessness values, reported on the 0 to 10 modified Borg breathlessness scale, after activities when using the app are shown in Table 2. The mean Borg breathlessness score was 3.8 (SD 1.3).

Table 2. Frequency for Borg breathlessness values recorded by the experiment group.

Breathlessness value (modified Borg scale)	Number of events recorded in the app
1	8
2	18
3	32
4	65
5	34
6	3
7	3
8	1
10	1

Difficulty Values Selected

The frequency at which participants selected the various difficulty or intensity options in using the app is shown in Table 3. Higher numbers represented greater difficulty for a given physical activity task. All difficulties were roughly equally represented, with no evident skew to higher or lower difficulties.

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Table 3. Frequency for difficulty values selected by the experiment group.

Selected difficulty	Number of events recorded in the app
1	36
2	47
3	36
4	46

Game Engagement

People with COPD in the experiment group completed 3 measures of subjective game engagement: IMI, GEQ, and a series of CPCA questions developed for this study.

The scores on the IMI subscales are shown in Table 4. The highest scores were seen for the value and usefulness subscale, with a mean of 6.4 (SD 0.6). All other subscales had lower scores, ranging from approximately 5.1 to 5.7.

Table 4. Intrinsic Motivation Inventory subscale scores (7-point Likert scale).

Subscale	Score, mean (SD)
Interest and enjoyment	5.4 (0.5)
Perceived competence	5.7 (1.0)
Effort and importance	5.3 (0.9)
Value and usefulness	6.4 (0.6)
Relatedness	5.1 (1.1)

The total score for the 19 items of the GEQ for each participant is presented in Table 5. The GEQ score totals ranged from 19 to 39, with a mean GEQ total score of 30.4 (SD 6.9). As this scale has a minimum possible score of 19 and a maximum possible score of 57, a score of 30.4 represents 30% (11.4/38) of the distance between these extremes.

Table 5. Total scores for the Game Engagement Questionnaire.

Participant	Game Engagement Questionnaire score
2	28
4	36
6	35
7	26
8	30
10	39
12	19

The results for each individual question in the CPCA questionnaire are presented in Table 6. Participants generally had a moderate to high degree of agreement across all questions, ranging from 5.2 to 6.5 on a 7-point Likert scale. Mean scores were higher for items relating to their health goals (items 1-3), all of which had a mean of 6.5 (SD 0.8).

Table 6. Cognitive processing and cognitive engagement individual item results.

Question	Score, mean (SD)
CPCA1[a]: Using the game gets me to think about my health goals (n=8)	6.5 (0.8)
CPCA2: I think about my health goals a lot when I'm using the game (n=8)	6.5 (0.8)
CPCA3: Using the game stimulates my interest to learn more about achieving my health goals (n=8)	6.5 (0.8)
CPCA4: I spend a lot of time using the game, compared to other ways of being physically active (n=8)	5.4 (1.4)
CPCA5: Whenever I'm trying to be more active, I usually use the game (n=5)	5.6 (1.5)
CPCA6: The game is what I usually play when I think about being physically active (n=5)	5.2 (2.4)

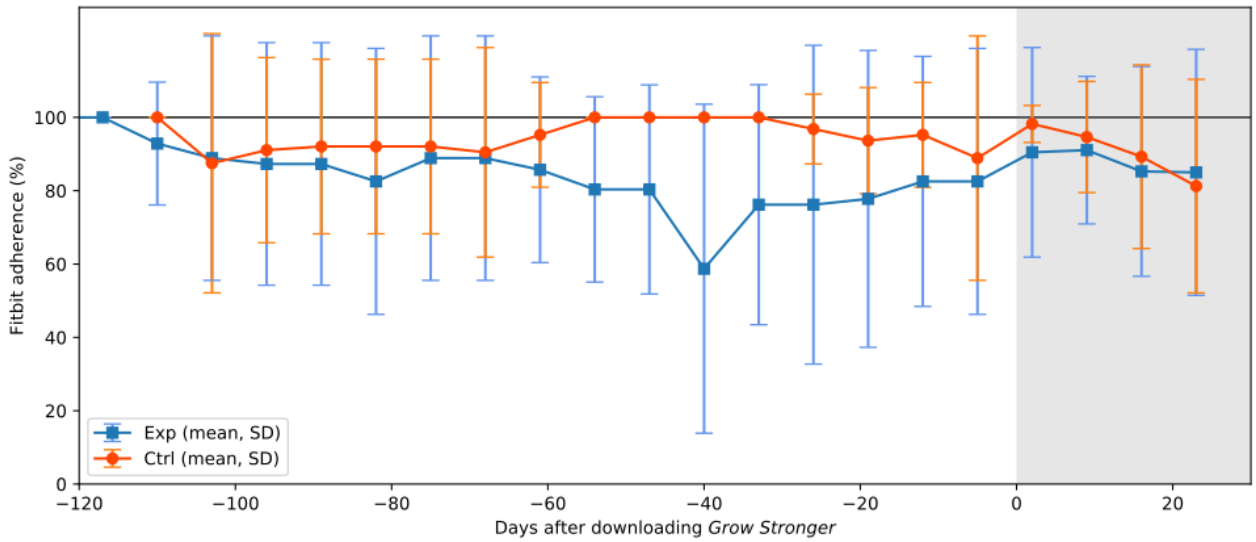
[a]CPCA: cognitive processing and cognitive activation.

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Fitbit Wear Adherence

Figure 5 shows the weekly average adherence to Fitbit activity trackers for participants across the study period, as calculated by days with a nonzero step count divided by total days and expressed as a percentage. Overall, participants in the control group had a slightly higher average adherence than the experiment group, wearing the Fitbit on 94.5% (1069/1131) of days compared with 84.3% (975/1157) of days in the experiment group. This was especially evident during the middle of the study period when adherence in the experiment group decreased for several weeks.

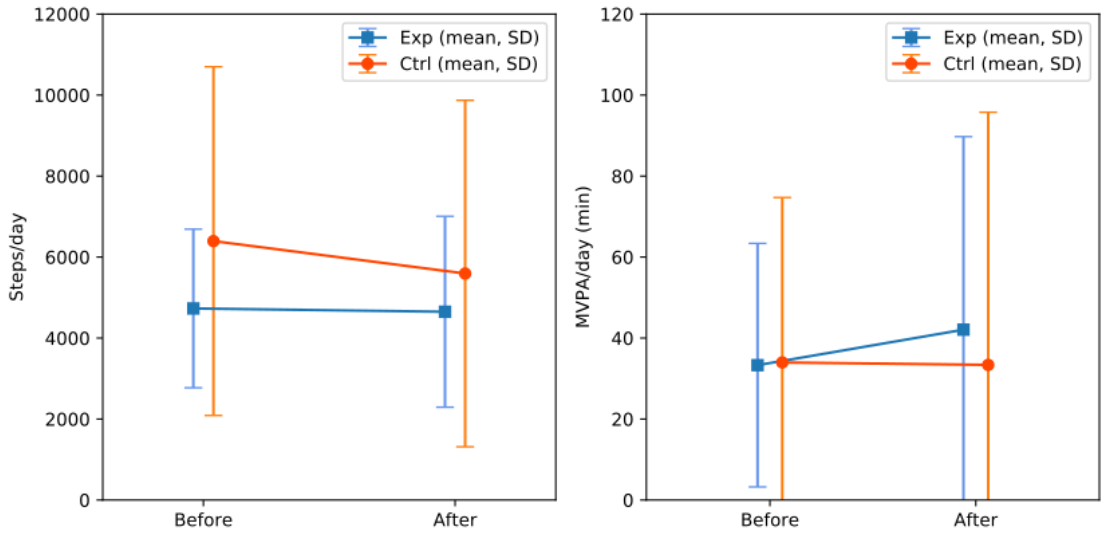
Figure 5. Average weekly adherence to wearing Fitbits in each group before and after the Grow Stronger app was downloaded by the experiment group. The period where each participant had downloaded the game is indicated by the shaded background. The control group, which did not download the game, were aligned with the majority of the experiment group for ease of comparison. As weeks are assumed to start on Mondays, but most participants downloaded the game on a Friday (day 0), the value for the final week before the game was downloaded (the last week in the unshaded area) included values from days 1 and 2 after the game was downloaded. All participants are included in the data presented in this figure. Ctrl: control; Exp: experiment.



Steps

Across all weeks before the game intervention was downloaded, the experiment group averaged 4730 (SD 1959, range 1493-7522) steps per day, as shown in Figure 6. Steps in the experiment group in the weeks after downloading the *Grow Stronger* AVG averaged 4649 (SD 2357, range 1853-8130) per day, representing a decrease of 81 steps per day or a 2% decrease. In the period before the experiment group downloaded *Grow Stronger*, the control group was averaging 6394 (SD 4306, range 2700-15,000) steps per day, which then decreased by 800 steps per day (800/6394, 12.5%) to 5593 (SD 4277; range 1924-14,367) steps per day.

Figure 6. Average steps per day and MVPA per day in each group before and after the game was downloaded. Ctrl: control; Exp: experiment; MVPA: moderate-to-vigorous physical activity.



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Individual step count charts for each participant are shown in Multimedia Appendix 2 for the experiment and control groups.

MVPA

As shown in Figure 6, before the game intervention was downloaded, the experiment group was averaged 33 (SD 30; range 3-76) min of MVPA per day, and in this period, the control group had an average daily MVPA of 34 (SD 41; range 3-120) min. During the game intervention, the experiment group was averaging 42 (SD 48; range 2-122) min of MVPA, and the control group was averaging 33 (SD 62; range 1-182) min of MVPA each day. This represented an increase of approximately 9 min per day or a 26% increase for the experiment group and an approximately 1 min or 2% decrease for the control group per day.

Correlations Between Outcome Measures

To explore the relationships within and between the secondary outcome measures (pre-post change in MVPA and steps) and the primary outcome measures (game adherence, game engagement on GEQ, and game engagement on IMI), the Spearman correlation coefficients were calculated. Table 7 shows the results in the form of a correlation matrix (a scatter matrix for these comparisons can be found in Multimedia Appendix 3). There appeared to be a moderately high positive correlation, with a Spearman rank correlation coefficient of 0.62 between the pre-post change in daily step and the usage of the *Grow Stronger* app (as assessed by percentage of days during the test period with at least one activity logged). Physical activity was weakly correlated with game usage. The total score on the GEQ correlated moderately strongly and positively with the mean score on the IMI, with correlation coefficients of 0.61. The pre-post change in daily steps appeared to be strongly negatively correlated with both the subjective measures of game engagement, with correlation coefficients of −0.79 for the GEQ and −0.71 for the IMI. The subjective measures of game engagement (GEQ or IMI) did not appear to correlate with changes in daily MVPA or to game adherence.

Table 7. Spearman rank correlation matrix between primary and secondary outcomes in the experiment group.

Outcome measures	Spearman rank correlation				
	Δ[a]Moderate-to-vigorous physical activity per day	ΔSteps per day	Game usage	Game Engagement Questionnaire	Intrinsic Motivation Inventory
ΔModerate-to-vigorous physical activity per day (pre-post)	1.00	—[b]	—	—	—
ΔSteps per day (pre-post)	0.21	1.00	—	—	—
Game usage (percentage of days with activities logged on Grow Stronger)	0.45	0.62	1.00	—	—
Game Engagement Questionnaire	0.21	−0.79	0.07	1.00	—
Intrinsic Motivation Inventory	0.19	−0.71	−0.19	0.61	1.00

[a]Δ: change in.

[b]—: These cells are deliberately left blank. The table is symmetrical about the diagonal, so the data are not repeated.

Discussion

Summary of Primary Findings

This study assessed the feasibility of the AVG intervention by measuring usage of the AVG in the experiment arm of this pilot trial and adherence to wearing Fitbit activity trackers in both the experiment and control arms. The usage of the game in this study was moderate, with participants who used the game recording at least one activity on 58.6% (82/141) of the days. This is slightly lower than the usage rates reported in the first few weeks of similar studies of apps or websites for physical activity promotion. For example, 68% of users of the gamified *Active Team* app were accessing the gamified app each day by day 7, although this fell to 31% by day 91 [45]. However, usage of *Grow Stronger* was measured by days with logged activities; therefore, it may be expected to be lower than a usage measurement based on days where the intervention was merely accessed. The difference between these 2 methods of measuring usage was illustrated by the pilot trial of *ActivityCoach* (Roessingh Research and Development), which found that participants visited the website an average of 23 times over 4 weeks but filled in the daily symptom diary just 16 times on average [46]. Similarly, in the pilot trial of *Condition Coach* (Roessingh Research and Development), which included a website with a symptom diary and exercise module, the website was visited on 86% of the days available, but the exercise module was only completed on 21% of the days [47]. Although the pilot trial lasted 9 months compared with just 3 weeks in this study, adherence to the *Condition Coach* exercise portal was clearly low throughout: only 5 of the 12 participants completed any exercises in the exercise portal. In comparison, 8 of the 9 participants completed at least one activity in *Grow Stronger*. However, these other apps were able to send notifications to participants during these trials, whereas our *Grow Stronger* app lacked the ability to provide notifications, which may have improved usage if it was available.

The Fitbit was worn on 84% of the days by participants in the experiment group and on 94% of the days by participants in the control group. These values are comparable with those reported by Wan et al [48], where pedometer wear adherence ranged between 80% and 90% in people with COPD. It is worth noting, however, that this pedometer was worn on the hip, pocket, or with a lanyard, in contrast to the wrist-worn Fitbits provided in

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this study. Adherence is thought to be higher for wrist-worn activity trackers than hip-worn in adolescents [49], although several participants in our study reported skin irritation, which may have decreased wear adherence.

Difficulty options selected in the app by participants were roughly equally distributed, indicating that the difficulty options presented were adequate for participants with COPD. Reported Borg breathlessness values were clustered around 3 to 5 on the modified Borg scale, indicating moderate shortness of breath and representing an appropriate target for exercise in people with COPD [50].

Engagement with the game in the experiment group as assessed on the GEQ averaged 30.4, out of a minimum possible score of 19 and a maximum possible score of 57. This is comparable with the GEQ results originally reported during the development of the GEQ, which were generally around 30 to 32 for adolescents and undergraduates playing common video games [39]. However, the result in this study is lower than the score given by healthy adults for AVGs [51], which would have corresponded to a score of 42 if the adapted GEQ with a seven-point scale used in that study was transformed into the three-point scale used in this study and in the original development study of the GEQ. The scores on the GEQ found in this study may be lower than that seen by other games because several items on the GEQ assess the subjective experiences of immersion and flow that may not be elicited by a game, such as *Grow Stronger*, which does not provide real-time feedback to players. GEQ results for games similar to *Grow Stronger* are unfortunately not available for comparison.

Participants in the experiment group appeared to have given a higher average rating for the value and usefulness subscale of the IMI than other subscales such as interest or enjoyment, relatedness, and effort or importance. This would suggest that participants were primarily motivated to play *Grow Stronger* because they saw value in it rather than because they enjoyed the game, felt a degree of relatedness to other players, or were motivated to put effort into it. It is possible that by being involved in the design of the game from its inception, participants in this trial were especially aware of the value or potential usefulness of the game. In addition, it has been shown that multiplayer AVGs offer greater relatedness than single player ones [52], so designing *Grow Stronger* to provide the option of a single player experience in addition to multiplayer may have diluted ratings on the relatedness dimension.

The CPCA scale showed somewhat higher mean scores for health goal questions than physical activity questions, indicating that participants primarily associated the game with achieving health goals rather than performing physical activity. This could be because of the design of the game, which allowed players to perform physical activity away from their smartphone and then to return to their phone to play *Grow Stronger*. This temporal asynchrony between being physically active and playing the game may have decreased the association between the game and physical activity, whereas participation in the design process may have increased the association between playing the game and reflecting on health goals. As this scale was significantly modified for the purposes of this trial, no comparisons to other studies are available.

It is also noteworthy that a response rate of around 41% (37/89) was observed among participants invited to participate in this study. Although we cannot determine the reason for nonresponse, some may not have responded because of lack of access to, or reservations about, technological interventions. A recent survey of people with COPD attending pulmonary rehabilitation in metropolitan areas of Australia found that 48% had personal access to a smartphone and 57% felt that their technology skills were adequate or better [53]. Nonetheless, the results of that survey and the engagement of participants in our study suggest that a substantial portion of people with COPD are willing to use technology in their rehabilitation.

Summary of Secondary Findings

In addition to the primary findings mentioned previously, this study also examined the effect on daily steps and daily physical activity levels of the combination of the *Grow Stronger* AVG and Fitbit activity tracker with the Fitbit app, compared with the Fitbit activity tracker with the Fitbit app alone, in patients with COPD. A noteworthy finding of this study was that the experiment group performed an average of 9 min more MVPA after downloading the game, whereas the MVPA in the control group remained roughly similar. Although these results must be interpreted cautiously because of the low sample size of this pilot trial and the large sample SD in the results, this nonetheless suggests that the AVG may have a positive effect on physical activity in this population. To the best of our knowledge, no published research has examined the effect on physical activity of a mobile game intervention combined with a wearable activity tracker versus an activity tracker alone in patients with COPD.

Another secondary finding of this study was that the average steps per day decreased by 13% in the control group but only by 2% in the experiment group. Despite the large variability in this small sample, this finding is consistent with the hypothesis that AVG could ameliorate the decline in physical activity often experienced after pulmonary rehabilitation [18]. It is also possible that the activity tracker itself caused an initial increase in daily steps, which slowly waned over the duration of the study before being partly counteracted by the effect of the AVG in the experiment group. Other studies of people with COPD have, however, examined the combination of activity trackers with mobile apps to encourage daily steps [23]. These mobile apps were not considered games and lacked clear game features but did incorporate behavior change techniques (such as self-monitoring, goal setting, and social support) that could have an effect similar to game design elements. For example, Moy et al [54] and Wan et al [48] compared the effect of a pedometer alone to the same pedometer combined with a website intervention, which encouraged incremental goal setting, allowed social communication between users, and provided educational and motivational messages. These studies, respectively, showed steps per day increased 13% in the intervention group, with no significant change in the control group at 17 weeks [54], and an increase of 19% in steps per day in the intervention group versus a decrease of 5% in steps per day in the control group after 13 weeks [48]. These 2 studies

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demonstrated an increase in the steps for the intervention with little change to the control group, whereas we found little change in the experiment group but a decrease in the control group. A decrease in daily steps in the control group was also observed in a trial of a mobile app that enabled clinician feedback combined with activity tracker compared with activity tracker alone at 3 or 6 months [55]. However, in contrast to this study where daily steps decreased only in the control group, in that study, both the control group and the experiment group decreased steps per day by approximately 14%. Vorrink et al [55] suggested that either the use of a smartphone app rather than a website or the involvement of health professionals could have contributed to the lack of difference between groups, but the *Grow Stronger* intervention used in this pilot trial was also a mobile app and also involved clinicians, yet a difference between groups was observed. Furthermore, although both Moy et al [54] and Vorrink et al [55] used activity tracking websites or apps that were specifically designed for users with chronic diseases, only the intervention used in a study by Vorrink et al [55] consulted people with COPD during the design phase and only after the initial design had been developed [56].

The observed change in daily steps was positively correlated with game usage, indicating that those who used the game more often also had a greater increase (or smaller decrease) in daily steps. This is consistent with walking, which is the most commonly recorded activity in the game. A correlation between game usage and MVPA was also present but weaker than that between steps and game usage. A stronger correlation between game usage and physical activity may have been expected, given that a recent study found that those in the top quartile for the usage of a gamified smartphone app, *Active Team*, increased their daily physical activity by 18 min (around 17% of baseline), whereas users in the lowest 3 quartiles of app usage decreased their daily physical activity by 8 min (around 8% of baseline) [45]. Physical activity in that study was assessed by research-grade accelerometry rather than the wearable activity tracker provided to participants, as was used in this study. It is possible that Fitbit activity trackers did not count toward the MVPA measurement of the short bouts of strength training that the *Grow Stronger* app encouraged participants to do.

Surprisingly, subjective game engagement, as measured on the GEQ and IMI, appeared to be negatively correlated to steps but not correlated to MVPA. This is contrary to the implicit hypothesis that the engaging nature of AVGs would encourage both more steps and more physical activity. This also conflicts with the results of other AVGs in other populations such as children, where an increased level of intrinsic motivation and enjoyment were correlated with increased physical activity [57]. It is possible that those who found *Grow Stronger* most enjoyable were more likely to have performed other forms of physical activity encouraged by the app, such as upper limb strength exercises, in place of their usual walking. If strength training could not be readily detected as MVPA by the Fitbit, this would not appear as a correlation between game engagement and MVPA. Possible reasons for the negative relationship between subjective game engagement and physical activity remains speculative, as no other studies have examined this relationship in the context of either smartphone AVGs or AVGs for older adults.

Subjective measures of game engagement did not appear to be correlated with game usage, which is contrary to a previous study that demonstrated a correlation between the IMI rating of a smartphone game to improve physical activity and the usage of said game [58]. However, the correlation in that study was assessed before and after a 24-week intervention in a group of 18 people with diabetes. At just 3 weeks with only 9 people with COPD, this study may not have been long enough for a correlation between game usage and subjective game enjoyment to arise or be large enough to detect whether such a correlation did exist. In addition, that study [58] employed a linear regression rather than the Spearman correlation as used in this study, precluding direct comparison between the 2 studies.

Limitations

This study is limited in several ways. As a pilot trial with a small number of participants and short duration, with the sample size, and trial duration oriented around the co-design process, this trial was underpowered to detect differences in steps and physical activity, which could be expected from such a short intervention. A larger and longer duration trial would be required in the future to gain a meaningful estimate of the effect of the AVG on daily steps and physical activity. In addition, participants in the experiment group were co-designers of the intervention, so they may have been more invested in the game that they helped to create. Therefore, this study's results may not be generalizable to a population who are naïve to the game.

Furthermore, the trial period formed part of the design process, with feedback from participants used to develop a final version of the game intervention beyond the test version trialed in this study. Therefore, the results of this study do not account for the effect that these revisions may have had on the effectiveness of or adherence to the final version of the game, which will be tested in future studies. For instance, the version of the *Grow Stronger* app used in this study was not able to record usage data regarding when participants accessed the app for purposes other than to record the completion of an activity. As such, no data were available on how often participants used the pause button feature or used the app to interact with one another or check their individual or team progress. Similarly, as mentioned, the app was unable to send notifications, and app usage was likely lower than it would be with reminder notifications enabled. The future version of the app will address these limitations.

As this pilot trial was embedded within a co-design process, the control condition was selected without full knowledge of the eventual design of *Grow Stronger* and so may not have been an ideal comparison. The control group received Fitbit activity trackers and the Fitbit app under the assumption that the AVG provided to the experiment group would most closely resemble the Fitbit app, albeit in the form of a game. However, as a result of the co-design process, *Grow Stronger* more closely resembled a mobile exercise diary. As such, future studies aiming to explore the effect of the game elements of *Grow Stronger* on physical activity should compare this game with a mobile exercise diary app that functions similar to *Grow Stronger* but

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lacks game elements. In addition, the use of any digital technologies in COPD may not represent the usual standard of care for people with COPD. Therefore, future research may also compare *Grow Stronger* with usual care of people with COPD after pulmonary rehabilitation, namely, providing a control group with an entirely unsupervised home exercise program.

In this study, activity outcome measures were recorded by commercial-grade Fitbit activity monitors, rather than a research-grade physical activity monitor, which presents 2 main limitations. First, although older hip-worn Fitbit devices have been shown to have a good correlation with research-grade activity monitors [21] in people with COPD, this study was conducted with newer wrist-worn Fitbit activity monitors for which such validity data are not known in COPD. The wrist-worn Fitbit Charge 2 devices used in this study have shown high validity for step counts but only moderate validity for MVPA when compared with research-grade accelerometry in older adults [59]. Second, the Fitbit devices were part of the intervention given to both groups, and data from such devices were visible to participants, which may have caused participants to alter their physical activity in response. Future studies may therefore benefit from employing accelerometers with established validity for MVPA and concealing such measurements from participants.

It is also worth noting that the CPCA questions used herein, although they were based on previously validated scales, were modified significantly to fit the purposes of this study and so may no longer retain their validity. Future research should seek to validate these measures or use alternative validated measures.

Finally, no objective tests of lung function or functional status were performed, nor were results from such tests available for this trial. Although it is very likely that all participants had COPD, as they all had attended a pulmonary rehabilitation class that requires referral by a physician, future research may benefit from confirmation of a clinical COPD diagnosis. In addition, the results of spirometry or exercise tolerance tests could be used to appropriately stratify participants in a future trial.

Conclusions

To our knowledge, this is the first study that trials an AVG designed by people with COPD and clinicians to maintain or enhance physical activity levels. Although the results are limited because of the small sample size, this study is an initial demonstration of the potential value of an app that facilitates physical activities for people with COPD. Future work is required to further improve adherence and to investigate the long-term effects of this intervention. Despite this, the *Grow Stronger* app shows promise as an intervention worthy of a larger-scale trial in this population.

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Screenshots and description of the Grow Stronger smartphone app.
[DOCX File , 698 KB - games_v9i1e23069_app1.docx]

Multimedia Appendix 2
Daily step counts for individual participants in the experiment group and control group.
[DOCX File , 307 KB - games_v9i1e23069_app2.docx]

Multimedia Appendix 3
A scatter matrix for correlations between the primary and secondary outcome measures in the experiment group.
[DOCX File , 73 KB - games_v9i1e23069_app3.docx]

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Abbreviations

AVG: active video game
COPD: chronic obstructive pulmonary disease
CPCA: cognitive processing and cognitive activation
GEQ: Game Engagement Questionnaire
IMI: Intrinsic Motivation Inventory
MRC: Medical Research Council
MVPA: moderate-to-vigorous physical activity

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Original Paper

A Bowling Exergame to Improve Functional Capacity in Older Adults: Co-Design, Development, and Testing to Compare the Progress of Playing Alone Versus Playing With Peers

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Abstract

Background: Older people often do not meet the recommended levels of exercise required to reduce functional decline. Social interaction is mentioned by this cohort as a reason for joining group-based exercises, which does not occur when exercising alone. This perspective shows that exergames can be used as motivational resources. However, most available exergames are generic, obtained from commercial sources, and usually not specifically designed or adapted for older people.

Objective: In this study, we aim to co-design and develop a new exergame alongside older participants to (1) tailor the game mechanics and optimize participants' adherence to and enjoyment of exercise; (2) test the participants' functional capacity, motivation, and adherence to the exergaming program; and (3) compare these scores between those who played alone and those who played with peers.

Methods: We conducted a co-design process to develop a new exergame adapted to older people. For user testing, 23 participants were divided into 2 groups to play individually (alone group) or to compete in pairs (with peers group). They played the game twice a week, resulting in 21 exergaming sessions. We assessed the participants' General Physical Fitness Index (GPFI) before and after the user testing. We also administered questionnaires about the gaming experience and exercise adherence with its motivators and barriers.

Results: We introduced a new bowling exergame for Xbox with a Kinect motion sensor that can be played in single or multiplayer mode. For the GPFI measurements, the sample was homogeneous in the pretest (with peers group: mean 40.5 [SD 9.6], alone group: mean 33.9 [SD 7.8]; *P*=.11). After the exergame testing sessions, both groups had significant gains (with peers group: mean 57.5 [SD 8.7], *P*=.005; alone group: mean 44.7 [SD 10.6]; *P*=.02). Comparing the posttest between groups, it was found that the group in which participants played with peers had better outcomes than the group in which participants played alone (*P*=.02). Regarding the gaming experience and exercise adherence, both groups recognized the benefits and expressed enthusiasm toward the exergame.

Conclusions: The findings suggest that the developed exergame helps in improving the functional capacity and adherence to physical exercise among older people, with even better results for those who played with peers. In addition to leading to more appropriate products, a co-design approach may positively influence the motivation and adherence of participants.

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KEYWORDS

functional status; elderly; virtual reality therapy; user-centered design; software design; video games

Introduction

Functional capacity expresses an individual's capacity to perform submaximal activities [1]. For older people, decreased functional capacity may negatively influence the performance of daily activities and everyday life, interfering with the person's independence, which is directly associated with impairments in functional performance [2,3]. To reduce functional decline, health professionals recommend physical activity, as it positively influences physical aptitude, cognition, and overall health conditions [4]. Frequent and regular physical exercise is an appropriate recommendation, as it can prevent numerous age-related declines, improve functional capacity, and improve quality of life [5,6]. However, despite the advantages of exercise routines, physical inactivity is highly prevalent among older people, and they might find it difficult to meet the minimum recommended activity levels needed to maintain health benefits [7-9].

The search for appropriate and attractive ways to engage older people in physical exercise is a challenging process [10]. In this perspective, exergames are presented as safe and beneficial resources for the practice of physical exercises by older people [11,12]. This type of game uses motion sensors to capture the player's actual movements, stimulating physical interaction [13]. Exercise routines based on digital games are promising to keep players physically and socially motivated [14-16]. In addition, they present motivational factors such as performance evaluation and feedback, which may reduce dropout rates [17,18]. However, a considerable part of the available exergames is from commercial sources, generally not designed exclusively for older people or based on specific protocols [19]. Furthermore, a generic approach is not the best solution to engage older people; thus, exergames need to be personalized to match their goals and performance levels [11].

Studies indicate that the practice of physical activity when performed alone does not show good adherence by older people because of the lack of motivation [20,21]. In contrast, social interaction is the central aspect mentioned by older people as a reason for joining group exercises [22-24]. Practices that combine the advantages of group-based exercise instructed by a professional can increase effectiveness through a personalized program with specific exercise routines, keeping older people motivated to exercise [10,25]. Socializing, either through cooperation or competition, has been investigated as a motivational factor mentioned by players who prefer exergaming with peers [26,27].

Although several studies report that exercising with other people influences the motivation of older people, further research is needed to verify whether the practice of exergaming in the same conditions as the conventional exercise may increase adherence. In addition, studies should verify whether exergames can positively affect the health outcomes of participants. We assumed that an exergame designed specifically for older people could produce better outcomes and engagement. Before implementing an exergame, the needs, wishes, and motivation of the intended players should be assessed, for example, by applying user-centered design methods [11]. Moreover, different processes and activities should be considered to increase engagement in the exergame [11]. A co-design process can significantly contribute to product development, reducing social stigma, empowering users [28], and giving voice to patient groups in the creation process [29]. This study has 3 objectives. First, we intended to co-design and develop a new exergame alongside older participants to tailor the game mechanics and optimize their adherence and enjoyment for exercise. Thereafter, we tested the participants' functional capacity, motivation, and adherence to the exergaming program and compared these scores between those who played alone and those who played with peers.

Methods

Recruitment and Participants

We conducted a co-design process and tests with 23 older participants who attended Caixeiral Campestre Club, based in the city of Passo Fundo, Rio Grande do Sul, Brazil. The inclusion criteria were as follows: participants who reported practicing some type of physical activity at least once a week before this study and who agreed to pause it during the testing period. All participants also had to have prior knowledge about the use of any type of technology, such as smartphones, computers, or video games. Men and women older than 60 years were accepted if they had cognitive aptitude attested by the Mini-Mental State Exam [30], which we administered before the intervention. As exclusion criteria, we excluded participants who reported having been discouraged by a physician to practice physical activity, had been hospitalized in the past 20 days, or would not have been able to attend all gaming sessions. Written informed consent was obtained from all participants. The local ethics committee of the University of Passo Fundo approved all procedures involving human participants under the opinion number 2.784.343.

For the test procedure, participants were separated into 2 groups: the *alone group*, initially with 11 participants who played the exergame individually, and the *with peers group*, initially with 12 participants who played the exergame, competing in pairs. Participants were allocated to the groups on an alternate basis by the order of agreement to participate. Throughout the tests, the pairs could watch each other play. As they were colleagues at the club, they also frequently talked about the game even outside the test sessions.

Game Co-Design and Development

The development team consisted of 3 fitness trainers, 2 software developers, and 3 human-computer interaction specialists with prior experience in game development for older people. A multidisciplinary team was fundamental for project development, encouraging communication between professionals and participants. The human-computer interaction

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specialists assisted in enrolling participants for the co-design practice and specifying aspects of game interaction such as esthetics, gameplay, levels, scoring, competition, and other features. Fitness trainers explored the possibilities of training exercises, assisted with gameplay orientations, and assisted with the levels of difficulty, according to the body movements required to complete the actions in the game.

Our study was guided by 3 main aspects, which examined the interface design, game design, and player experience [31]. For game design and development, we applied a co-design process using experience-based design theory, based on the method described by Askenäs et al [32]. We also followed the guidelines formulated by Planinc et al [33], which consider the development of exergames controlled by body movements designed especially for older players. The guidelines include the use of appropriate gestures, minding the physical condition of the participants and avoiding small objects. Planinc et al [33] also mentioned the encouragement of social interaction and that the exergame should be adjusted to the interests of older people, based on activities that are familiar to them.

Following the co-design actions, in the first stage of the process, the development team had 6 meetings to discuss aspects related to technology, game design, testing, purpose of the study, and expected results. The meetings were held once a week for approximately 50 min at the club where the tests would be performed. In the meetings, other exergames developed and practiced specifically by older people were investigated to ascertain what aspects and characteristics should be incorporated in the development of a game for this target audience.

In the second stage, we set up the co-design group, which included the development team and members of the club who were willing to participate in the design process. The contributions of the other team members helped encourage the user participants to join the group. All participants met at the same location and were introduced to each other and the objectives of the study. The pace of the meetings was controlled by the researchers to ensure that the process remained on track and that the procedures were fully understood by all participants. During 2 meetings, the group brainstormed ideas to discuss the types of games that older people would like to play. The team of professionals provided insights on the choice of gaming, each according to their expertise. The user participants suggested that they would like to play bowling, because of its similarity to the real-world game, that is, the way of playing was already familiar to them. They also stated that they would enjoy playing virtual bowling because it reminded them of the activity they practiced with family and friends.

The software developers believed that they could implement socializing and competition features in the bowling game. The fitness trainers affirmed that bowling was a suitable choice as the movements performed by the player are the same in the real and virtual world. Therefore, all members of the group agreed that bowling was the most appropriate choice of game. Bowling is a closed skill sport that requires fine-tuning and training of self-paced predefined movements as well as a high level of concentration and balance to completely knock down the pins [34-36]. This kind of game may also help prevent an inactive life, promote physical and cognitive functions, and result in entertainment and motivation with social presence [6]. Furthermore, bowling allows slow movements that correspond to typical physical activities that are recommended for older people [37]. In this sport, they can practice by performing body movements such as real sports where flexibility, abductions, and extensions of the lower and upper limbs are required.

In the third stage, the group described the main tasks, activities, requirements, and objectives that they believed should be a part of the game. The tasks were designed to be simple in structure to facilitate user understanding and attention span. Some exergaming concepts were analyzed, and a few design ideas were tested. After this stage, possible design solutions were elaborated, building ideas on how the game could be presented to users, from sketches following the overall concept and the information collected in the previous stages. Participants could freely explore and express their thoughts. No detailed models were expected as the data collection method was new to the user participants.

The game was implemented using a Kinect v2 motion sensor (Microsoft Corporation) and motion capture technology to guide and immerse the avatar in a 3-dimensional (3D) environment. The game is compatible with devices running the Windows operating system (Microsoft Corporation). We used Unity 3D (Unity Technologies) as the game engine, Blender (Blender Foundation) for modeling and texturing the game objects, and Adobe Fuse (Adobe Inc) for the creation and modeling of the 3D characters. When the first stable version of the game was concluded, we began the tests. Throughout the testing period, the group reported feelings and impressions about the game, including difficulties, problems, and improvements that could be implemented. The technique used to gather information at this stage was observation and the think-aloud method to collect the participants' immediate feedback [38]. All collected information was implemented during the testing period. As new characteristics were implemented, the game was updated for the sessions with the user participants. This process is characterized as iterative, in which activities and assessments must be repeated until a satisfactory solution is found [39]. The iterative development process helped researchers reliably collect tangible data. At the end of this study, everyone who was a part of the research met in a focus group to ensure that the results met the genuine needs of older people and to clarify previous experiences and impressions, considering each member's vision and level of satisfaction with the game developed.

Outcome Measures

We used the following measurements to assess participants and their interaction with the game:

- The Senior Fitness Test [40] was used to assess functional capacity and obtain the General Physical Fitness Index (GPFI). It consists of 6 tests designed to assess physiological parameters associated with independent functioning: lower and upper body strength, aerobic endurance, lower and upper body flexibility, and agility and dynamic balance. Numerous studies have shown that functional capacity can be assessed with several instruments

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to provide important diagnostic and prognostic information in a wide variety of clinical and research settings [1].

- With the Physical Exercise Adherence Questionnaire [41], we used the 13 yes or no statements of motivators and 12 yes or no statements of barriers for exercising, in this case, related to the exergame. Picorelli et al [41] developed and validated this questionnaire in Portuguese, which was adapted for the Brazilian older adult population, considering Brazil's cultural, economic, and social contexts.
- Game Experience Questionnaire (GEQ) [42] was used to characterize players' gaming experience during and after the gaming session. We used its in-game and postgame modules, which contain 14 statements and 17 statements, respectively, with a semantic differential scale response ranging from 0 to 4. Each component score is computed as the average value of its specific items. GEQ has been widely used in traditional game studies [43] and studies dealing with exergames including older participants [44].

Testing Procedure

In the pretest, participants were interviewed in a predetermined setting on the club premises. On that occasion, a fitness trainer administered the Senior Fitness Test to all participants. In the test period, participants from both groups played the exergame in sessions twice a week, resulting in 21 exergaming sessions. This twice-weekly design and the 10-week duration were defined based on an average of similar studies [3,10]. Each participant had 10 rounds per session, with 2 throws each, regardless of whether the player scored points. There were 10 throws with the right arm and 10 throws with the left arm. Therefore, each participant had 20 throws, resulting in approximately 10 min of gameplay per session. A fitness trainer followed all sessions and instructed participants on the gameplay rules. For the with peers group, the throws were interspersed between the 2 participants of the pairs, who played competing and seeing the opponent's score on the game screen. During the testing period, participants were not allowed to perform any other type of physical exercise. After the gaming test period, all participants had their functional capacity reevaluated using the Senior Fitness Test. The participants also answered the GEQ and Exercise Adherence Questionnaire.

Statistical Analysis

Quantitative data were analyzed using the SPSS 22.3 statistical package (IBM Corp). We performed Wilcoxon signed intergroup comparisons based on negative posts to obtain the GPFI through the Senior Fitness Test for pre and posttest in both groups. We also performed Mann-Whitney tests with signed intragroup comparisons. We performed Mann-Whitney *U* test with signed intragroup comparisons to analyze the GEQ scores. All analyses considered a 95% CI (significance for $P \leq .05$).

Results

Game Evolution

We intended to design a playful experience in which the physical movements themselves would contribute to the meaning of the game. The first contact participants had with the game was with a simpler first version, which had only one character and no sound effects. In this version, the game consisted of 2 distinct scenarios, one with the main menu and one with the bowling alley and surrounding bleachers, both with simple and homogeneous textures. The menus and the scoreboard of the rounds had only basic features.

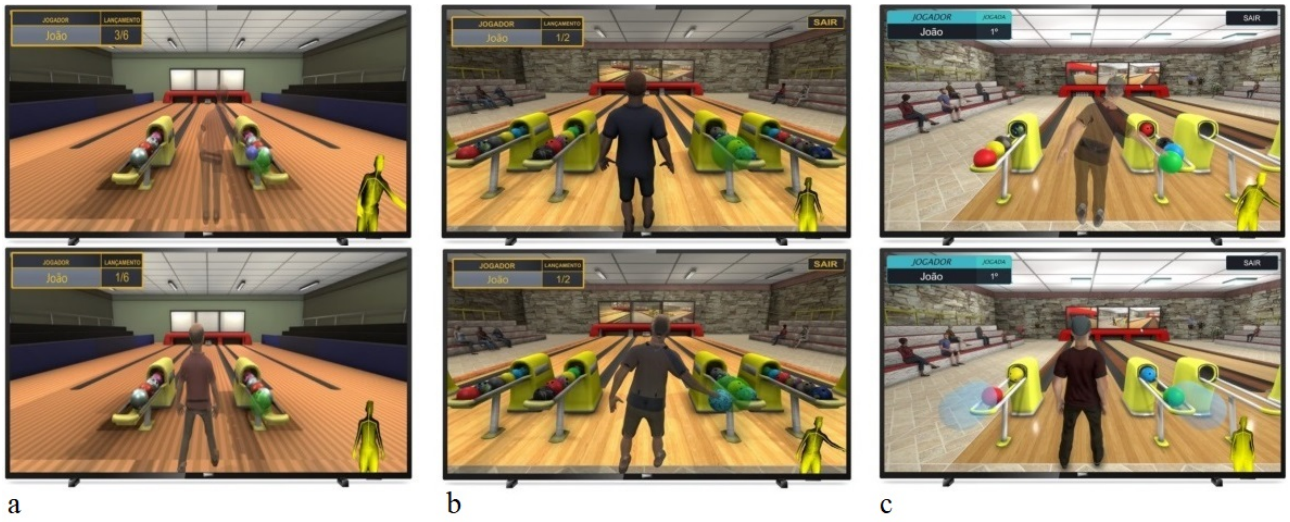
During the testing period, configurations and improvements were implemented gradually, according to the need observed in the interactions through the participants' reports. The game scenario was set with realistic texturing. Background songs were added to the home menu and for the game rounds. Rolling ball and falling pins sound effects were also added. Later, we included the option to return to the menu during the game without closing it. In that version, a female avatar was included, as the participants questioned the absence of such a character. In the menu implementation, we added the input of the participant's name, gender, and age as well as a ranking with all registered players' scores. Various colors and textures of bowling balls were also added and randomly chosen when the participant had to catch the ball to throw. In that version, the ball was set at a variable speed, according to the player's throwing strength.

For the intermediate version, the characters were replaced by 6 new ones, 3 from each gender. The characters resembled older people. The bleachers were composed of a cheering audience to motivate the participants. We updated the instance system for balls, pins, scores, and match history. The pin counting and replacement system were simplified, and the balls on the rack were no longer static as before, as they had to be instantiated and rolled through the rack to be released. The participant could choose the character and start the round using an arm gesture.

For the final version, the interface was redesigned with new colors and harmonic proportions, including the option of gesture interaction to go through the menus. Four more character options were added, resulting in 10 different characters. Strike and spares counts were added. At the end of the game, it reported the accuracy and performance of each player based on their score. A complete match history was implemented. New camera animations and unified scenes were added. When there was a strike, confetti effects appeared in the scenario, and the audience cheered. In the menu, we added options for sound volume, sensor distance, and activation of gesture interaction. The lighting system and scripts were optimized, and new background sounds were added. Figure 1 illustrates the evolution of the exergame with the 3 versions used over the testing period.

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Figure 1. Screenshots showing the evolution of the bowling exergame versions in its (a) first version, (b) intermediate version, and (c) final version.



The final developed exergame, called *Boliche Virtual*, has 2 game modes, one for single players and another to be played in pairs (multiplayer). The Brazilian National Institute of Industrial Property granted us the software copyright registration code BR5120190019121. The game works similar to the real-world 10-pin bowling game, which consists of 10 frames. In each frame, the player has 2 chances to knock down as many pins as possible with the bowling ball. When playing with peers, 2 players are interspersed in each round. Each dropped pin equals 1 point; therefore, the maximum score a player can obtain is 200 points per session. The game's sequence and scoring system is not entirely similar to the actual bowling system, as it was designed in a more straightforward way to facilitate understanding and gameplay for older players. The total scores for each round, strikes, and spares were stored. At the end of the gaming session, the game announces the winning player and shows the accuracy of each player, ranging from 0% to 100%. Multimedia Appendix 1 provides the screenshots and details of the bowling exergame's final version.

Participant Characteristics

At the end of the gaming sessions, 19 participants completed the tests (age: mean 68.9, SD 5.3 years). In the with peers group, there were 10 participants (7 women and 3 men) with a mean (SD) age of 68.8 (5.2) years. However, in the alone group, there were 9 participants (6 women and 3 men) with a mean age of 69.1 (SD 5.8) years. The loss of testing was because of the participants' loss of interest. All participants were retired, living in the city where the study was performed, and had a higher education level. Although all participants had already used some type of technology, all said that they had never interacted with an exergame before this study. No statistically significant differences were observed between the groups across the baseline demographic variables of gender (P=.89), age (P=.90), education level (P≥.99), or prior knowledge about exergames (P≥.99).

User Testing

Table 1 shows the statistical results of the GPFI score pretest and posttest. Initially, considering the pretest, the sample was homogeneous (P=.11, Z=−1.603). Both groups showed significant gains from the exergaming sessions (P=.005 and Z=−2.807 for the with peers group; P=.02 and Z=−2.273 for the alone group). Comparing the posttest between groups, the with peers group had significantly better results than the alone group (P=.02, Z=−2.416).

Table 1. General Physical Fitness Index results.

Test	Played with peers (n=10)	Played alone (n=9)	*P* value[a]
Pretest, mean (SD)	40.5 (9.6)	33.9 (7.8)	.11
Posttest, mean (SD)	57.5 (8.7)	44.7 (10.6)	.02
P value[b]	.005	.02	N/A[c]

[a]Intergroup comparison using Mann-Whitney *U* test.

[b]Intragroup comparison using Wilcoxon test.

[c]N/A: not applicable.

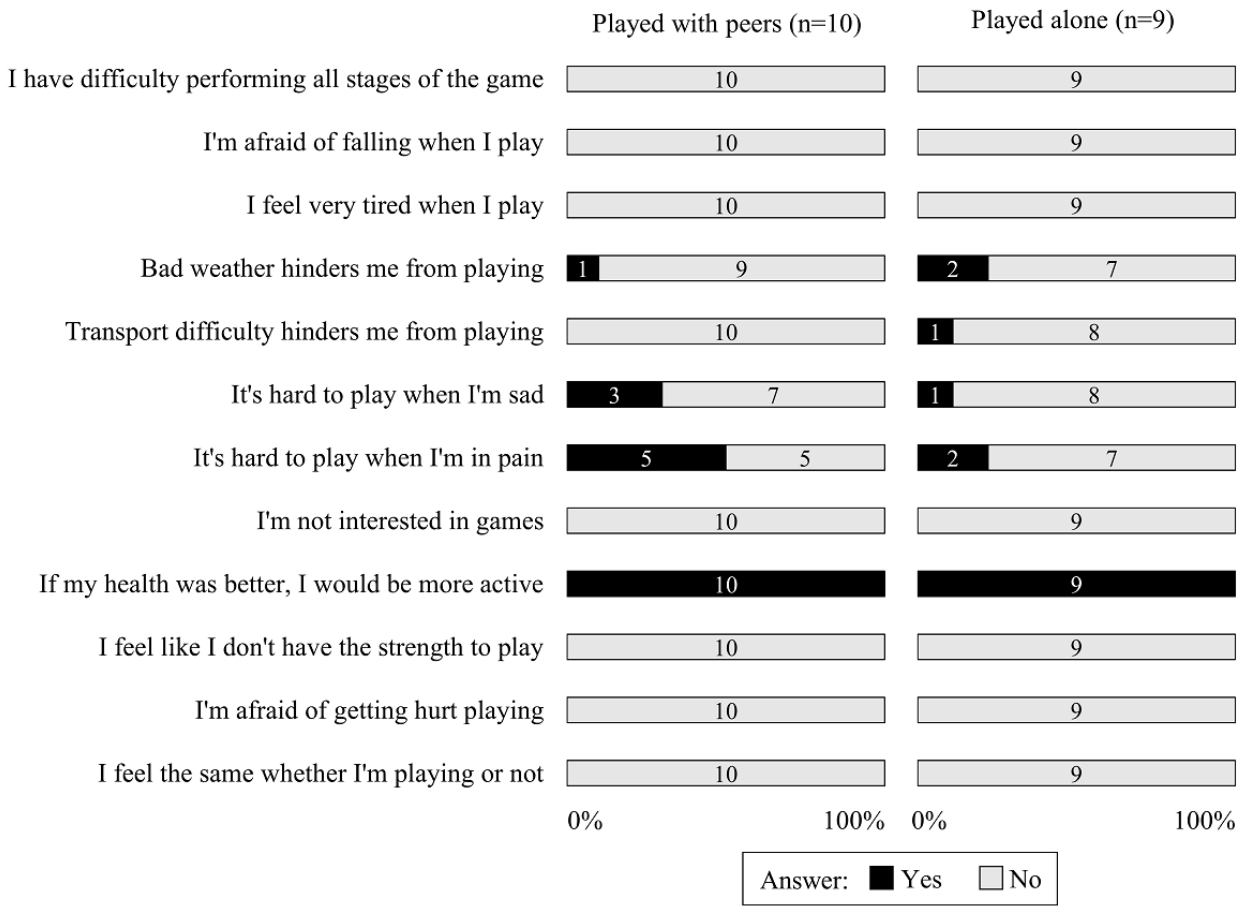
Figures 2 and 3 show the results of the Physical Exercise Adherence Questionnaire, with statements of barriers and motivators encountered by participants when playing the exergame. As for the motivator statements, the game was motivational for both groups. There was a significant difference between the groups for the statements "Groupmates would help me deal with my problems" (P=.04) and "I'd prefer group games to individual games" (P=.04), which had a greater agreement in the with peers group. With regard to the barriers faced by the participants, the with peers group showed higher percentages than the alone group in the questions "It is difficult to play when I am in pain" and "It is difficult to play when I am sad." In turn,

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several participants in the alone group reported that "Bad weather hinders me from playing" and "Transport difficulty hinders me from playing." Finally, all participants in both groups agreed that "If my health was better, I would be more active." In either group, no participant answered affirmatively to statements about tiredness, difficulty in use, and fear of falling when interacting with the game.

Table 2 shows the results of the GEQ scores and the comparisons with the Mann-Whitney U test, signed intragroup comparisons, with groups as the grouping variable. The only component with a statistically significant difference between groups was sensory and imaginative immersion, which had a higher average score for participants who played with peers. Although nonsignificant, the with peers group obtained a slightly higher average than the alone group in the competence category. In the categories challenge and flow, the values were higher but nonsignificant for the alone group. In the evaluation of participants' experiences after using the game, the tiredness category had no answers. For both groups, the tension category obtained a lower average of results compared with the other categories. Similarly, there were no answers linked to some aspects of the negative affect category. In contrast, both groups obtained a high average in the positive affect category.

Figure 2. Responses to the adherence statements about barriers when playing the bowling exergame.



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Figure 3. Responses to the adherence statements about motivators when playing the bowling exergame. The asterisk indicates *P*=.04 intergroup.

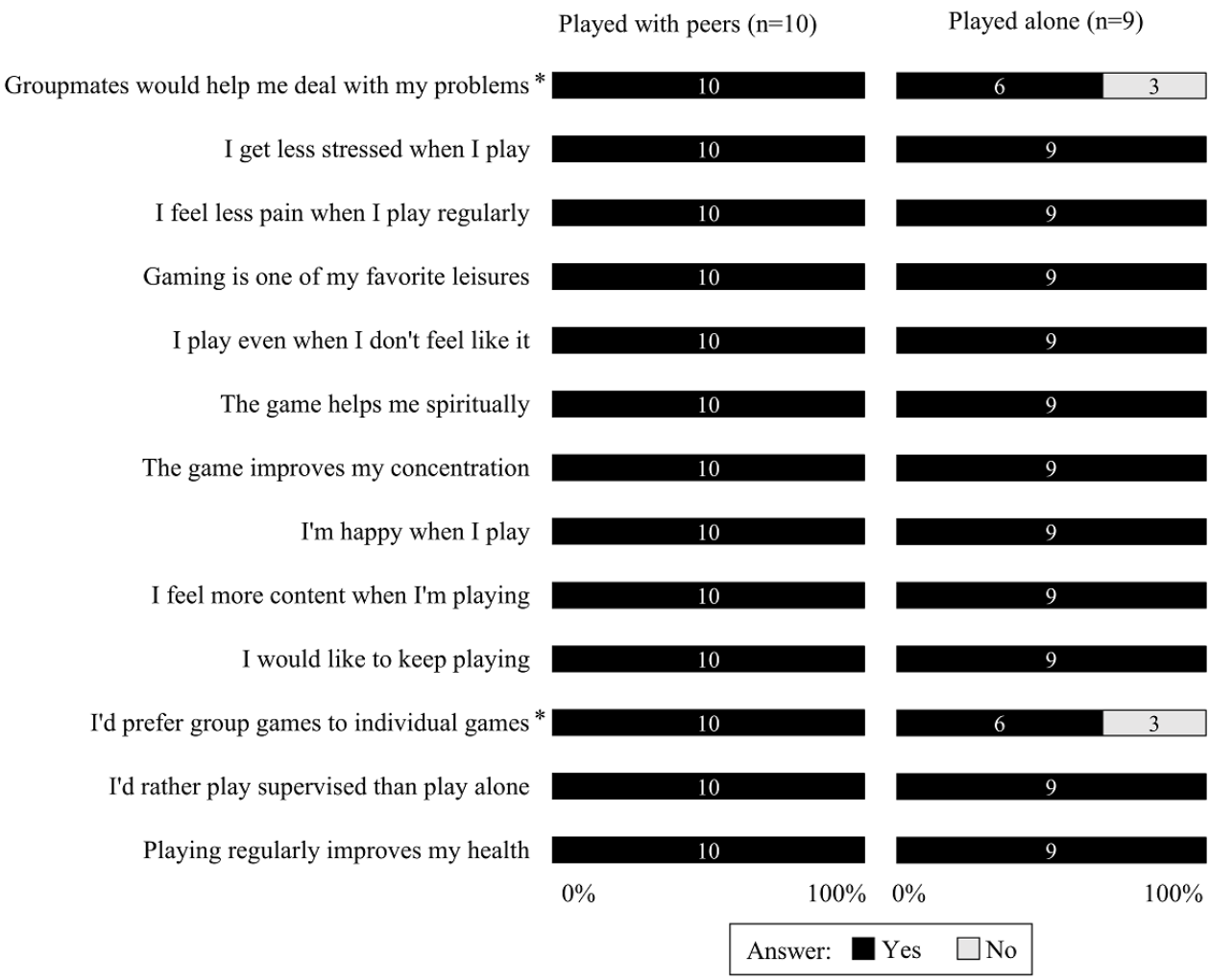


Table 2. Mean (SD) scores for the components of the Game Experience Questionnaire.

Module and component[a]	Played with peers (n=10), mean (SD)	Played alone (n=9), mean (SD)	*P* value[b]
In-game			
Competence	3.80 (0.26)	3.72 (0.67)	.55
Sensory and imaginative immersion	3.90 (0.21)	3.67 (0.25)	.05
Flow	3.85 (0.24)	3.94 (0.17)	.33
Tension	0.00 (0.00)	0.11 (0.22)	.13
Challenge	3.05 (0.90)	3.56 (0.68)	.18
Negative affect	0.00 (0.00)	0.00 (0.00)	>.99
Positive affect	4.00 (0.00)	3.89 (0.33)	.29
Postgame			
Positive experience	3.28 (0.08)	3.22 (0.25)	.92
Negative experience	0.67 (0.00)	0.74 (0.22)	.29
Tiredness	0.00 (0.00)	0.00 (0.00)	>.99
Returning to reality	1.07 (0.41)	1.04 (0.26)	.45

[a]Scores can range from 0 to 4.

[b]Mann-Whitney *U* test with signed intragroup comparisons.

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Discussion

Principal Findings

In this study, either playing alone or with peers, older participants showed significant improvement from pretest to posttest, reaffirming that the practice of exergame is a therapeutic instrument to improve the functional capacity of older people [45]. Nevertheless, the results also suggest that even better outcomes in individuals' functional capacity and adherence can arise from group-based exergaming, which is similar to the outcomes of group-based conventional exercise [46-48]. Technology is an innovative method to assist changes associated with aging. Supporting older people to participate in physical activity through evaluations offers the added benefit of tracking user activity by monitoring health events and behaviors in real time [49].

Other studies [23,25] suggest that, when comparing traditional exercise with exergaming, both modalities showed more successful results when performed in groups, which can significantly promote social interaction [37]. However, similar experiments [50] have revealed differing outcomes regarding exergaming alone or with peers. Thus, this type of finding deserves further investigation. In this study, we assumed that the participatory co-design process was a key determinant. Notwithstanding, participation in exergames can improve cognitive and physical skills that are directly involved in the functional abilities needed by older people in daily life [51].

Understanding the opportunities, challenges, and training processes that optimize the benefits of exergames has important implications for improving the quality of life and longer-term independence for older people [52]. According to Meekes and Stanmore [27], comprehending the motivation of older people to use exergames can help in the game development process. Thus, throughout the co-design and evaluation period of this study, users were part of the creation process. The contribution that the participant brings to the development of a particular product is crucial to its success, as, by participating in this process, users can see their suggestions being implemented before the product is completed, feeling valued during this process [53,54].

According to Zhang et al [55], the study of familiarity issues among older people is necessary to guide the interaction design of new technologies. Thus, they can be built upon the prior knowledge of older people on real-world interactions, making it easier to apply their existing knowledge and skills to a new domain. Zhang et al [55] also explained that 3 specific design aspects should be followed: representation as similar as possible to the real world to help older people understand the game; manipulation, which indicates how older people manipulate the objects in the exergame; and meaningful design, which includes the stimulation of the older people's memories and emotions. From a game design perspective, to increase the preference of older people's attitude toward exergames, it is necessary to consider games with more attractive and comprehensible elements so that the older people can enjoy playing [50,56]. In this sense, a co-design creation process can lead to tailormade challenges that are optimized to the participant's own preferred level of physical exertion.

In this study, older people were motivated to cooperate directly and indirectly in the game development, similar to what was reported by Chen et al [57] and Kappen et al [58]. We observed that all participants answered *no* to all statements about barriers that were directly related to the game itself. In addition, virtually all participants responded positively to all statements about motivators (241 of 247 individual responses). Furthermore, the participants' positive experience and interest in their co-designed exergames were evidenced by high scores for complementary components and low scores for derogatory components of the GEQ results.

Other studies highlighted the importance of including the user in the process of development, especially when considering older people [59]. Brox et al [60] reported their results from 3 years of research in the field, providing a user-centered protocol for exergames adapted to the needs of older people. According to the authors, the time devoted to the older people was the main element essential to establish communication and to earn the trust of each one of them. In addition, all types of game elements should be considered during the exergame project, even if they seem too obvious, and particular needs of this target audience must be met during the design process to make exergames more effective [61]. Considering the development of exergames for older people, Chen et al [57] state that playfulness and perceived utility are 2 of the main aspects that affect behavior and the intent to use. According to their study, older people's acceptance of exergames depends not so much on the fun when playing but on the perceived usefulness of physical and cognitive skills employed on it.

According to Bird et al [62] and Tobaigy et al [63], older people often lack knowledge and perception about how to interact with exergames and how their use can improve health care, until they are exposed to them. In this study, users began to feel comfortable with the game as the sessions progressed, gradually becoming familiar with the way of playing and identifying the benefits of exergaming. The results showed that the interaction with the exergames provided a friendly environment for social interaction, fun, and rehabilitation of the older people in both the groups. When assessing adherence to physical exercise from the motivators, we observed 2 statistically more positive answers in the with peers group to the statements about playing alongside other people. Social aspect was one of the main motivators that led older people to interact with exergames, as mentioned in other studies [10,20,25]. In this context, socializing refers to the interaction between participants, that is, the exchange of experiences facing the same challenge together and competition [64]. Older people can regularly play exergames not only to enhance their health but also to take advantage of the opportunities to socialize with others, which further increases their emotional well-being [50].

Most participants' experience with the exergames was considered positive. However, the sensory and imaginative immersion achieved a significantly better result for the with peers group, suggesting that the participants in this group became more interested in the game's story and found it

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impressive. The fact that playing with a peer is very similar to a real bowling game where participants compete with each other may have contributed to this result, as the exergame may have an effect similar to the conventional bowling game [65]. Usually, exergames use an avatar to represent a player in the virtual world. Studies suggest that the avatar's appearance may be a key factor that influences player behavior [66]. When choosing an avatar reflecting themselves, players have higher perceived game interactivity. This can be a powerful motivator, leading to higher engagement during gameplay. In this study, female participants reported that they felt more attached to the game when a female character was available to play. In addition, participants felt more captivated by the game during the final sessions when improved characters and new elements were added.

Limitations

Some limitations of this study include the fact that we only explored competition instead of collaboration among the user participants and the fact that the study had a small sample size because of dropouts, which makes it difficult to generalize the results. With regard to the study design, nonblinding may have negatively influenced the findings, although the groups were homogeneous in age and functional capacity. We had to rely on the participants' claims about not performing other physical exercises throughout the study, thus avoiding confounders. In addition, the bowling game has specific movements; other types of games may use different ones and therefore may not elicit the same outcomes. During the sessions, participants kept interacting with the game even when it was not completely ready in its final version. If participants had only interacted with the final version of the game, the results might have been different. In addition, participants attended the same club and became even more familiar with their peers throughout the sessions. In this sense, playing with stranger peers or in a smaller number of sessions would not necessarily lead to the same findings. Only older people who already practiced some physical activity participated in the experiment; therefore, the results do not necessarily apply in an equivalent way to older people with sedentary habits.

Conclusions

Exergames as motivators of physical activity have been increasingly seen as promising and encouraging tools. The findings of this study suggest that exergaming, either alone or with peers, leads to a statistically significant improvement in functional capacity. However, evidence suggests that an exergame is more attractive and successful when participants play it with peers. With regard to adherence to physical exercise, both groups showed interest in playing alongside other people. Another contribution of this study was the creation of the exergame *Boliche Virtual*. Our approach offered a collective experience with the use of technology, placing the user at the center of the game design process. This approach may have influenced the motivation and adherence of participants and, consequently, elicited better health outcomes. Therefore, co-design and testing using a participatory and iterative process might foster positive results.

More research applying this design approach is needed to understand the opportunities, challenges, and training processes that can optimize exergames to improve the quality of life and long-term independence of older people. In future works, we intend to perform new tests with a larger number of participants. Other aspects related to player experience can be assessed, such as decision making. We also suggest the long-term monitoring of the participants to verify the maintenance of results and to further investigate the differences in exergaming with peers.

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Authors' Contributions

JJ, DB, and EB share first authorship, conducted major parts of the methods and experiment design, and contributed to the majority of the writing and reviewing of the manuscript. OB contributed to developing the software and drafting part of the manuscript. LD and AP provided methodological support and conducted the statistical analysis. HF provided methodological suggestions and critical review for the text. AM supervised all stages of this study, including conceptualization, methodology, validation, and text review.

Conflicts of Interest

None declared.

Multimedia Appendix 1
Screenshots and details of the bowling exergame's final version.
[PDF File (Adobe PDF File), 1349 KB - games_v9i1e23423_app1.pdf]

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Abbreviations

3D: 3-dimensional
GEQ: Game Experience Questionnaire
GPFI: General Physical Fitness Index

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Original Paper

Utilizing Theories and Evaluation in Digital Gaming Interventions to Increase Human Papillomavirus Vaccination Among Young Males: Qualitative Study

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Abstract

Background: Human papillomavirus (HPV) is the most common sexually transmitted infection in the United States. HPV attributes to most cancers including anal, oral, cervical, and penile. Despite infection rates in the United States, recommendations and communication campaigns have traditionally focused on females. Because of this, males lack knowledge about reasons for vaccination, the benefits of being vaccinated, and their HPV risk, overall. Gaming as a health education strategy can be beneficial as mechanism that can promote behavior change for this key demographic because of the popularity of gaming.

Objective: We sought to explore the relationship between gamification and HPV vaccine uptake.

Methods: Interviews were conducted with experts (n=22) in the fields of cancer prevention, sexual and reproductive health, public health, game design, technology, and health communication on how a game should be developed to increase HPV vaccination rates among males.

Results: Overwhelmingly, theoretical models such as the health belief model were identified with key constructs such as self-efficacy and risk perception. Experts also suggested using intervention mapping and logic models as planning tools for health promotion interventions utilizing a digital game as a medium. In game and out of game measures were discussed as assessments for quality and impact by our expert panel.

Conclusions: This study shows that interventions should focus on whether greater utilization of serious games, and the incorporation of theory and standardized methods, can encourage young men to get vaccinated and to complete the series of HPV vaccinations.

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KEYWORDS

digital games; behavior change; theory; evaluation; game design; health care providers

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Introduction

According to the Centers for Disease Control and Prevention, human papillomavirus (HPV) is one of the most common STIs among adolescents and young adults [1]. Approximately 14 million new cases of HPV occur in the United States each year, with nearly 80 million people estimated to be currently infected [1,2]. An equal opportunity virus affecting both men and women, HPV can be spread easily during skin-to-skin contact during anal, oral, or vaginal sex [2,3]. Routine vaccination starting in early adolescence (aged 11 or 12 years) can prevent common HPV infections and their associated diseases, such as oropharyngeal and cervical cancers [1,3,4]. In comparison to females, males are less likely to be partially or completely vaccinated [3,5,6]. While there are 3 approved vaccines for use in the United States that are covered by insurance, vaccination rates remain low among young men [1,6].

The HPV vaccine has been available to males since 2009, and in 2019, the Advisory Committee on Immunization Practices recommended catch-up vaccinations among this population, with certain special populations being immunized up to age 26 years [1,5]. Yet, recent statistics have shown that because of the lack of or delayed symptoms with HPV-associated diseases, adolescent and young adult males are at a higher risk for certain HPV strains than adolescent and young adult females [3,4,7]. To date, there is no approved HPV test for men. Furthermore, routine screening is not recommended by the Centers for Disease Control and Prevention for HPV-related diseases that may be associated with anal, penile, or oropharyngeal cancers [3]. According to one major study [5], males lacked knowledge about HPV and perceived no benefit to getting the vaccine. In this same study, they were also unaware that they could be given the vaccine and did not receive any HPV-related recommendations by their health care providers [5]. Additionally, socioeconomic and behavioral factors, including substance abuse, racial and ethnic disparities, sexuality, distrust of the health care system, stigma, and lack of access to health care have increased the spread of the STI [5,8]. With that being said, innovative strategies need to be employed to facilitate the uptake of this vaccine.

Access to digital materials has been shown to be a highly effective method of receiving, retaining, understanding, and actionizing health information [9]. The use of interactive games (also referred to as serious games) has increased in popularity among health professionals as a viable educational tool and behavior intervention strategy for addressing health disparities. Gamification is the use of digital game mechanisms in a nongaming context to engage users, motivate activities, and solve problems. Gamification can prove to be better than traditional programs and interventions because digital games provide immediate feedback when the player takes an action or selects an option within the game. Because of this feedback (negative or positive), players are able to correct their decisions or make changes to their strategy. This feedback is beneficial to the user because it allows for increased cognitive processing and experiential learning [10,11]. When designing a serious game, gaming components should be based on behavioral theories that are capable of measuring its impact and effectiveness on individual-level determinants [12]. Interactive digital interventions including health promotion games that are based in theory, such as the self-determination theory [13,14]. and dual-processing models of cognition, were effective in educating and reducing the risk of STIs including HPV [15].

While gaming has been utilized in many domains, very few have explored gaming for vaccination uptake within public health. Furthermore, of the games developed around the influenza and general vaccinations, they have been widely researched as preventive and care engagement tools. In a systematic review [16], published in 2016, that highlighted these games, none utilized behavioral change theory. Additionally, they lacked specific evaluation methodologies and long-term assessments of the games [16]. To our current knowledge, there is only one interactive game that exclusively explores improving HPV vaccination for boys and girls aged 11 to 12 years [13]. In a 2019 study [17] conducted in Norway, researchers developed and released a mobile HPV game [17]. However, this game was not theory-based and is only meant to increase awareness and knowledge of HPV. A game that is developed as a health intervention must have the ability to be appropriately evaluated and engaging [18]. In the absence of standardized evaluation methods for serious games, design principles (ie, usability, playability, and visualization) are incorporated into designing a gameplay experience that does not distract the user from the intended outcomes. This must be simultaneously balanced with meeting user expectations of a gaming experience that combines challenge, fantasy, and curiosity [19]. Recent work has begun to explore digital gaming to improve HPV and HPV-related vaccine outcomes among young men [20], but to date, little attention has been focused on designing and evaluating an evidence-based serious game targeting HPV vaccination tailored for young men.

This study seeks to explore the relationship between gamification and HPV vaccine uptake. With this approach, we will examine (1) theoretical models that would be most useful in game design to increase HPV vaccination rates in young males aged 18 to 26 years and (2) explore evaluation study designs for digital-based gaming. As an area with limited research, digital games that incorporate theory and integrate evaluation may have the potential to normalize perception of sexual health and STI prevention and to improve vaccination rates among this population [8].

Methods

Participants

This study was approved by the University of Florida's institutional review board. Experts were recruited from the fields of sexual and reproductive health, cancer prevention, public health, game design, and technology and health communication to collect qualitative data. Because the topics of HPV and gaming are interdisciplinary in nature, we aimed to get at least 2 experts from each of the fields mentioned above to participate in the interviews. Besides the disciplines within which experts were employed, sampling was not done based on any other variables. A nonrandom purposive sampling approach was implemented to ensure heterogeneity with respect to expert

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backgrounds. Experts were initially identified based upon their publication record, word of mouth recommendations, and body of work or experience. Initially, a total 18 experts were contacted and invited to participate in the interviews. All 18 experts accepted the invitation to participate in the study. A snowball method of interviewee identification and selection was also employed to recruit additional participants. At the end of each interview, experts were asked whom else the research team should contact to participate in the study. An additional 6 experts were referred and invited to participate based on their relevant areas of expertise. One of the referred experts declined to participate.

Procedure

The purpose of the interviews was to elicit in-depth input and recommendations to explore the current state of games for health research and practice and strategies for using games as a means to promote and improve HPV vaccination rates among college-age men. In-depth interviews were carried out with the identified experts who were contacted via email and invited to participate in the study. If the response was positive, a telephone or in-person interview was scheduled by research staff.

The interviewee was provided with a copy of the interview guide (see Textbox 1) and informed consent form prior to their interview in an effort to help them prepare. Interviews were conducted using open-ended questions. All interviews were audiorecorded, and each participant was made aware of the audiorecording when they gave their verbal or written consent to participate in the study. Interviews lasted an average of 80 minutes and were conducted by the same member of the research team in a location conducive to private conversation. Interviewees were not compensated for their time but were very willing to participate due to their interest in the purpose of the interview. Because the experts had participated in interviews before, combined with the training of interviewers, all interviews were conducted in one round and sufficient detail was provided. Interviews were carried out by the first and fourth authors who were trained in qualitative research inquiry.

Textbox 1. Expert interview questions guide.

1. What's your experience in HPV research or just HPV?
2. Have you had any experience in game development design and/or testing?
3. Would you recommend someone using a digital game to improve sexual health outcomes? And why or why not?
4. What do you think are some of the benefits of using digital games for sexual health?
5. What do you think are some of the challenges of using digital games for sexual health?
6. Do you think that college men would be receptive to using a digital game about the virus and about the vaccine? And why or why not?
7. When you think of a game, a digital game aimed at increasing in particular risk perception of the HPV virus and vaccine uptake, what health messages do you think would be most beneficial for college aged males and why?
8. What features or characters should be included in the game for college age men to increase their risk perception for the virus?
9. What features or characteristics do you think would be more instrumental for increasing risk perception?
    - What game mechanics would be beneficial for increasing risk perception?
10. What features or characteristics do you think would be more instrumental for increasing HPV vaccine uptake?
    - What game mechanics would be beneficial for increasing HPV vaccine uptake?
11. If you were to design a game on the vaccine itself how would you foresee that being done? Specifically the development and designing of the game?
12. What are the most relevant theories, models, or evaluation strategies for HPV vaccine programs targeting college age students?
13. How should we evaluate the game for quality and impact?
14. How would you define success in a game for health behavior change related to the HPV vaccine?
15. Are there any other advice or recommendation would you give to someone developing a game for HPV for college age men?

Data Analysis

Interviews were transcribed verbatim by trained transcriptionists. Transcripts were organized and coded across all 22 interviews. Using grounded theory, emergent themes were identified and reported [21]. To establish reliability, 2 independent researchers individually coded each transcript. Coding was conducted in rounds and researchers coded 5% of each transcripts then met to discuss the identified codes. By the second round all differences were discussed, and a final coding scheme was established. This approach was continued until all of the transcripts were completed. After coding, the data were sorted by themes and subthemes with accompanying quotes for clarity and organization. A matrix was used to identify patterns within the data to be explored.

Results

Overview

The results reported in this study reflect only a portion of the data collected from the study. Specifically, results discuss the

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use of theory, program planning models or approaches, and evaluation strategies that should be employed in game design and development pertaining to the HPV prevention and uptake of the HPV vaccine for college-age men.

Theories and Theoretical Constructs

The experts who were interviewed emphasized that any gaming intervention designed for males should incorporate theory. Some theories that were mentioned in the interviews included social progress theory, social cognitive theory, normative theory, psychosocial theories, elaboration likelihood model, theory of reaction, theory of reasoned action/planned behavior, lifestyle risk deduction model, theory of gender and power, transtheoretical model (stages of change), health belief model, extended parallel process model), theory of triadic influence, integrative behavioral model, diffusion of innovation, and Anderson health care utilization model. Although interviewees either worked in research, government, or academia, collectively, they all encouraged the use of behavioral theories. In particular theories that focused on increasing a male's perception of benefits and addressing those key barriers that could prohibit HPV vaccine uptake were highly regarded. This resulted in the health belief model being highlighted frequently.

Of the behavioral theories, constructs most mentioned being instrumental to the intervention design included perceived susceptibility, risk perception, and self-efficacy (see Table 1). In fact, 17 of the 22 interviewees mentioned self-efficacy and highlighted self-efficacy as one of the predictors of behavior change. In addition to HPV vaccine self-efficacy, consideration of gaming self-efficacy was encouraged. While men of all ages are the highest gamers, gaming self-efficacy is predicated on making sure that whatever is designed is easy enough that people with that confidence voluntarily engage in gameplay and continue this behavior [22]. Apart from self-efficacy, risk perception was the second-most mentioned theoretical construct in the qualitative interviews. While risk perception is instrumental to the uptake of the game (ie, feeling though you are at risk which encourages you to play the game to learn how to reduce your risk), interviewees felt as though highlighting that risk within the game and engaging within game risk reduction activities would be most influential to end game and out of game behavior. Overall, the two most mentioned theoretical constructs (self-efficacy and risk perception), were both components of the most frequently cited theory (health belief model) in this particular study. Thus, strengthening the health belief model's appeal as the theoretical foundation that should be used when developing a digital gaming intervention around HPV and the HPV vaccine.

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Table 1. Theory or theoretical construct quotations.

Frames	Quotations
Health belief model	"In this age group, I think—and I've not done work with this age group, its speculation—but based on different behavioral change theories, you know, breaking down some of those barriers, 'Where can they get the vaccine?'; 'Is there a cost attached to it?'; 'What are the benefits to them, specifically?'; 'What are the benefits to their relationships, that they care about?'; 'What are the potential side effects to the vaccine' and being able to sort of weigh those against the majority of the benefits that they would experience"
	"To implement your program more than anything. But if you're talking, that's not, that's not really a theory so if you're really talking about actual theories, I mean I would say more the Health Belief Model. Cause I know it was developed to...to explain vaccinations"
	"Well, health belief model is the one that's used a lot in sexual health because it looks at perceived susceptibility of a disease or other threat and then kind of cues to action and perceived benefits"
	"I mean cause like for example, you know, you could say well people may not know where to go to get the HPV vaccination. They may think that they may have to go to the health department, they may not have health insurance... it could be a situation they could get it for free like those sorts of things. So, applying each individual... concept of the Health Belief Model, I think would be, would be really good. I think there is a very tangible, applicable, applicable way to do it"
Self-efficacy	"But you know the game while it can make them behave in a certain way, which is cool, because that is one of the advantages of the game, but it can translate to reality, we only really are targeting the cognitive things, so even when I do it I'm not only playing the game but I'm potentially changing my cognition, my behavioral capability, my self-efficacy, my knowledge and maybe that's going to change my intention of behavior"
	"That's a lot more interesting, and from a theory perspective, I can bide with that that's building self-efficacy because you're engaging in the behavior, even if it's simulated."
	"So, you've, you know you're going to have to apply methods that will boost that self-efficacy. So, you are probably going to be using things like persuasion, modelling, um successive approximation to a goal maybe. So that makes me think about simulations, when you're thinking about the group because they could take an avatar and take them through what they think is a risk reduction behavior and see the results or not."
Risk perception	"You know so I think, things about genital warts, probably would be much more realistic, um, you know, improving risk perception and severity, you know, that's where a game I think will have um, a big impact, because its um, especially if it was the simulation where um, you know like that whatever plague is that they spread in World of Warcraft, similar to that, like how easy it is to be unaffected, that content takes only one time, you know colleges full of all kinds of risk behaviors as people figure out their identity and those coupled with drinking and things like that, and the fact that this is an STD does not necessarily get protection from using condoms"
	"Well I mean if it's risk perception is one. Low levels of risk perception is one of the determinants that are negatively influencing vaccine uptake. Then I think messages and of things like you know, 'Anyone can get it,' and maybe characters that have similar attitude of, 'Yeah I'm not— that's not going to happen to me,' and you know it spreads the misconceptions that then are addressed and I think that those kinds of things can help. Also, you know increasing information about risk, about the common-ness of the infection"

Program Planning Models or Approaches

In addition to theory, interviewees mentioned the role and impact of using program planning tools, approaches, and models to develop a gaming intervention for males. Items that emerged during the one-on-one interviews included intervention mapping and logic models. One interviewee preferred the intervention mapping approach because this model goes step-by-step thorough how to design an intervention program, which can also be applied to the game design and development process. Intervention mapping can also be of great benefit because it can help developers think of the determinants within the target population that should be considered and help the game be more effective. Social marketing was also mentioned as a possible dissemination tool to encourage game play and promote health among males (see Table 2).

Logic models are also an instrumental tool to program and intervention development in the fields of public health, health education, and health promotion. While it is an approach that is applied more in the traditional setting, it can be easily adapted to a virtual or technological setting. As discussed by the experts, logic models can provide a snapshot view of the entire intervention. This can include the processes that should be done beforehand (prior to game design) such as formative research and usability or beta testing, the strategies (game mechanics) that should be integrated into the game, the activities that should encourage game play and then the short-, intermediate-, and long-term outcomes that we would like to see to indicate success after the intervention is done.

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Table 2. Program planning models quotations.

Frames	Quotations identified
Intervention mapping	"So again I'm off topic, but I think intervention mapping is my recommendation because that's what we used here and I think it covers the basis and you can use it to the degree you want to use it in terms of the depth. But it basically says find out about the problem, come up with a concept of the solution, build a prototype to that, fix it and design, and figure out how you are going to disseminate it as well."
	"We usually, we always use an intervention map which is a-which is an approach to develop things any kind of intervention but it really helps you think through the, you know, the-the desire to change in whatever determinants and then make decisions about what are the message and the practical applications that could influence change in the determinant. So, so a systematic process for making decisions about the approach, I think, is critical."
	"Yeah I think that from a generic perspective I would probably recommend a process such as intervention or mapping. You've heard about intervention mapping.....Yeah, so that's really fairly well known. It's a pretty standard approach to develop an intervention. What it offers to this particular behavioral science and health education is it helps with determining health behavior. So, if your game is designed to encourage risk reduction behavior um, let's say, um then you will, you will expect to delineate the specific behaviors to, delineate the specific determinants like a social determinant of those behaviors. So you are talking about self-adequacy expectations, norms, perceived norms, whatever is important for those in your particular target population and it will sort of force you to really understand the nature of the problem and, the nature of the best delivery system"
Logic models	"So, I would do that first and then once we have that, what we do in this process that I mentioned is that we developed, you know, a logical model of change. And in that logical model of change you have the behavior that you want which in this case is probably vaccine uptake and completion of the, of the theory."

Evaluation for Quality and Impact

As with any health promotion program or intervention, it is important to evaluate it to determine its effectiveness. However, successful evaluation relies heavily on well thought out data collection and assessment activities. Because game design can be an expensive and lengthy process, our experts advised conducting alpha or usability testing to ensure that it captures what it needs to prior to final data collection and assessment. Apart from testing the gaming mechanics and features prior to the final development stage, they also encouraged thinking about the measures that are to be collected. More importantly developers should determine if the final measure will be collected as a pre- and post gaming intervention variable external to the game; or whether there a way to use built-in features within the game to collect data points. Measures for quality and impact discussed in the interviews included feedback from the players, message reception or acceptance, dissemination to others, social impact, and increased engagement or retention within the game. However, the greatest predictors of success, highlighted by experts, for a male gaming intervention included changes in knowledge and awareness, changes in behavior, and gaming to vaccine correlation (see Table 3). Ultimately, all interviewees who participated in our study highlighted the need to conduct process, impact, and outcome evaluations.

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Table 3. Evaluation for quality and impact outcomes quotations.

Frames	Quotations
Alpha or usability testing	"So I think, yeah I would tell people about this game or I would play this with my friends or, I believe this game is as good as other games that are related to health or how does this game compare to the games you play? Is it better or worse? More fun less fun? These are questions that we typically ask in usability but you can ask those type of questions. One of the questions I really like is 'how could we make this game better?' And the reason I like it is that it is positively oriented, its um, it's got an altruistic style to it and it really find out what sucks in the game without them having to say it, so it's really acknowledging the short fall of the game. So, it's like they can say I would really change up this and blah, instead of them having to endure the sort of social desirability problem of telling you this thing sucks"
	"Usability is giving it your user, a new player and asking the same questions. You can do usability by doing that. You could do it with a survey. You can also do talk aloud usability test. You get them to play it and tell you what is going through their mind so um well, I'm going to pick the pink button because they think that you know that's going to lead to a better result, I'm going to choose the middle door on my quest you know, why, I'm going to choose this avatar, why? We did our Asthma simulation, we found that the young males all gravitated to this older Hispanic woman who had this lighter color hair because she was just perceived as more attractive. So, you learn a bit about how you are presenting everything with that approach. So, then you may tweak it or you may think it's ready for a trial and you can apply it. You can get enough samples, that would give you the power to check the outcome and you can write a pre-post that randomize the laboratory conditions"
	Let's say it's a simple card game and so now we have all these cards and all these rules, we sort of think how are we going to play it and we play it amongst ourselves and we play it till we thin kits cool and we thin kits a good one, so let's now take it to some of our target population and see it too and check their responses. We haven't programmed something yet, we are still working with the concept and the rules versus a table game. So that is proof of the test of the concept and it's an acceptability test and a usability test. But, what we're asking, what we have the opportunity to look at is, questions that are looking for evidence like, ease of use, ease of play, um, understandability, acceptability, of this a s a game, um, credibility, I think the information here is trustworthy. The perceived value um so I think the information I am getting here will help me make better decisions in the future."
Data collection measures	"Um, so I think that part of it is super helpful, I mean, I like love self-measurement projects where its like already built in um, I mean I'm so, but, here's something, okay. It's actually something we are doing with google right now. It's really cool. Um, we have all these digital ads that are like measuring behavior physicians. So we know predominantly what websites these physicians frequent, you have our ads on there, they are exposed to various kind of ads, banner ads, PSAs, maybe a 6 second pre-roll that they can continue watching or mandatory 30 second yadda yadda. And we're actually able to use IP address chasing to determine if they have taken an action after seeing this. And um, those who have watched our 30 second video are 300 times more likely to then search around HPV vaccines and vaccinations"
	"I don't know how technology works but I think there are ways to do that relatively easily. Um you could say on some level just, you know one measure of success is that engaging and do they play it. And the other is does it actually have the desired effects. Maybe it has undesired effects like you wouldn't want to measure but behavior changes are often what the ultimate end goal but sometimes were harder to evaluate and practice"
	"if there's a point in the game on where to get the vaccine you can track to see how many people get to that point. If they get to the location maybe there's something on that end that they could verify, sort of prize or coupon or something like that. Obviously if you build in social media then you can track those analytics as well. I think you'd have a lot of data now. You can quantify that to success"
	"It just depending on what you want your audience to do. Do you want people to remember messages? So maybe you could build in a measure for recall. Send them an email in a month or something and give them a short quiz and see if they remember that stuff."
	"Pre and post the game playing. You could do behavioral stuff and then even long-term behavioral of your same cohort"
Gaming to vaccine correlation	"And I would think, that doing the same kind of measurement, that this would have to be a planned evaluation project from the outset where we are going to enroll 200 young men or whatever the number is and we are going to have them play this game, and we are going to naturally allow them to accept or not accept the HPV vaccine, we're going to find out what their rates were before and after that. We are going to pick HPV vaccine naïve men, so that we know how many get vaccinated or there could easily be a survey component in it too, because I think it's more than just one person being vaccinated"
	"Like...this is not the best evaluation but like pre-your game what percent of the students or whatever vaccinated and then after. Did you change it? You could even do like demand at the clinic"
	"So, if you're going to do this on college campus, maybe look at the pre vaccinations levels the university implements freshman orientation than game and then you look at the end of the year you look at the vaccination levels. Or the game can be more specific, questions for user have you gotten this pre vaccination? Maybe you can throw away a pop up that they can click on to get the vaccine"

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Discussion

General

In this study, we sought to examine the theoretical models that would be the most useful in game design for increasing HPV vaccination among adolescent and young adult males. We also explored an evaluation of study design topics (for creating digital games). Our major findings included the use of the health belief model and normative theory for game design. The major constructs that we found included perceived susceptibility and risk perception. Specifically, experts in sexual health, cancer prevention, health and communication, college health and wellness, and game development all found self-efficacy to be the primary construct for predicting behavior change. Other significant findings included the use of logic models and intervention mapping as program-planning tools and for evaluating effectiveness, measuring quality and impact, and conducting usability tests, all of which were essential in the front end of game design for this population.

Digital games that incorporate theories and integrate evaluation into their design can improve HPV vaccination among young males. Similar games for health that have used theoretical foundations have shown to be successful with changing behavioral outcomes. In a systematic review [23] conducted in 2015 on the development of digital games, of the 54 games were designed for health promotion, 7 focused on sexual health outcomes. Of the 7 games, 5 incorporated theoretical constructs in the design of the game and as outcome measures, and 2 specifically measured the effects of the games on behavior. While the sample was small, effect sizes were positive and significant for knowledge, self-efficacy and behavioral intention; which has great implications for overall behavior change [23].

While the focus of this study was college-age males who were not previously vaccination at 11 to 13 years old due to varying and outdated vaccine recommendations, the implications of this study can have greater impact upon younger adolescent age males. Benefits are especially prominent if implemented and used prior to sexual activity initiation to offer full protection against HPV-related cancers. Previous research has shown that theoretical models such as the health belief model show promise as theoretical frameworks for understanding for vaccine uptake among young adult males living in urban settings [24]. Our study clarifies the broader relationships between multiple theories and constructs (including the health belief model) that can be used to measure the impact of gaming on individuals, particularly for educating this population on the importance of HPV [18].

While there are several models that can be employed, the health belief model and its varying constructs have shown to be the best choice because of its proven application. Developed in the 1950s to explain why people did or did not participate in programs to prevent disease and illness, the health belief model is one of the most known and widely applied theories [25]. Specifically, in public health, it has been proven effective in behavioral interventions focused in areas such as health screenings, immunizations, vaccines, sexually transmitted infections, and cancer prevention [25].

In order to predict behavior change, the health belief model takes into account the perceived severity of the disease or illness, susceptibility to the disease or illness, benefits and barriers to performing a new behavior, and cues to action (motivators) to changing behavior. Often, perceived severity and perceived susceptibility are collectively referred to as perceived threat or perceived risk. Self-efficacy was later added to the theory, because the importance of one's confidence in their ability to change their individual behavior was identified as an important component to behavior change as well [26]. Therefore, when developing a digital game to increase vaccine uptake, one must take into consideration the self-efficacy of the players. Self-efficacy, perceived susceptibility to HPV, and extensive exposure to HPV-related information have been shown in previous studies to predict vaccine acceptance and uptake by young males [24,27]. Self-efficacy is an essential construct, as it regulates several cognitive processes for developing and maintaining behaviors [28]. These include confidence, control, and success with specific tasks [28]. In this case, the goal is to design a game that educates and creates an experience for an individual involving HPV vaccination and sexual health promotion using the identified theories and constructs. The aim is to develop behavioral skills that will promote consistent vaccination among this population.

This study also showed the importance of evaluating game design for quality, impact, and effectiveness. Logic models are essential because they provide an organized schematic depiction of the way theory and intervention intersect, and they can be useful for understanding how outcomes are produced for a given project [29]. Intervention mapping may also be useful in designing a game to promote HPV vaccination, as it is a systematic way of looking at a health problem, design materials, and protocols based on theory and practice [30]. Historically, beta testing a game for playability, usability, visualization, effectiveness, and quality has been essential to the evaluation of any serious game [19]. In all, these data suggest that understanding the purpose of theory and evaluation may have a profound impact on the quality of the game design and on what individuals learn about HPV, sexual health, and STI prevention.

The limitations of this study include the interviewees personal biases as qualitative researchers. Qualitative research can depend heavily on the skill of the individual researcher and is thus easily influenced by researchers' values and opinions. [31] Another bias could have emerged through the use of purposive and snowball sampling to recruit study participants. This type of nonprobability sampling often relies on the judgement and discretion of the researcher making it subjective in nature. It is also argued that this type of sampling technique is not truly representative of the entire population [32]. However because of the interdisciplinary nature of this project and specificity of the results targeting to a specific population that the methodology employed is not as much of a limitation overall. In fact, reviewing the data with peers and experts in the field can help one maintain objectivity in the data-analysis process. Another limitation is that the qualitative data gathered here are a subset of a broader data set. The overall volume of qualitative

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data can affect the analysis and the interpretation of the findings [33,34].

Future Implications

Although a large majority of interventions and programs are implemented in traditional health education settings, health care providers and nurse practitioners are becoming increasingly vital to increasing vaccination rates among adolescent and young adults [35,36]. Most often, these programs or approaches are implemented in health care settings and school-based programs. In clinical settings recommendations by health care providers are cited as the primary motivator for HPV vaccination of children by parents [37]. Therefore, there has been great discussion and emphasis on the nurse' role as a champion in promoting the HPV vaccine especially since they interact more with families during in clinic visits [35]. Alternatively, in a 2014 study [36], it was identified that public health nurses used a variety of strategies to increase the rate of HPV vaccination in schools. These included but were not limited to providing HPV health education sessions alongside an informative package, question and answer sessions, flexible appointments, the inclusion of males in health promotion activities, and communication through a variety of media formats such as the school newsletter and website [36].

Since the COVID-19 pandemic has affected medical visits and school-based interactions (because of social distancing, stay at home orders, and governmental bans), we have seen the number of vaccinations, including HPV vaccinations, decline dramatically over a short period [38]. Coupled with the already lagging vaccination rates, this is cause for concern [39]. With the increase of telemedicine and telehealth to respond to the need of health service provision, health care providers, public health practitioners, and nurses should consider gamification activities and digital games as a way provide accurate information and initiate behaviors that would lead to HPV vaccine uptake [40].

Consistently using data reduction methods can make the concepts and relationships in the interviews more visible [34]. The limitations notwithstanding, our findings contribute to the games for health literature from an evidence-based perspective. Future research should consider using focus groups with young men to aid in identifying salient content for a serious game intervention. Creating a safe space to educate young men around safe sex practices and vaccination can help to promote discussions around use, health benefits, and concerns about the virus and vaccine.

Conclusion

Research in this area should focus on whether greater utilization of serious games and the incorporation of theory and standardized methods can encourage young men to get vaccinated and complete the series of the HPV vaccinations. In analyzing the effectiveness of a digital game, the focus should be on change in uptake measures that include not only vaccination initiation but 3-dose completion. Moreover, individuals designing health interventions for practice should consider tailoring the design to role models and or opinion leaders within the community. By providing information and focusing on the rewards to vaccination, gaming can create a constructive learning model and make learning personalized, interactive, and fun.

Authors' Contributions

All authors wrote, reviewed, and approved the final manuscript.

Conflicts of Interest

None declared.

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Abbreviations

HPV: human papillomavirus
STI: sexually transmitted infection

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Original Paper

Preserved Inhibitory Control Deficits of Overweight Participants in a Gamified Stop-Signal Task: Experimental Study of Validity

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Abstract

Background: Gamification in mental health could increase training adherence, motivation, and transfer effects, but the external validity of gamified tasks is unclear. This study documents that gamified task variants can show preserved associations between markers of behavioral deficits and health-related variables. We draw on the inhibitory control deficit in overweight populations to investigate effects of gamification on performance measures in a web-based experimental task.

Objective: This study tested whether associations between inhibitory control and overweight were preserved in a gamified stop-signal task (SST).

Methods: Two versions of an adaptive SST were developed and tested in an online experiment. Participants (n=111) were randomized to 1 of the 2 task variants and completed a series of questionnaires along with either the gamified SST or a conventional SST. To maximize its possible effects on participants' inhibitory control, the gamified SST included multiple game elements in addition to the task itself and the stimuli. Both variants drew on the identical core mechanics, but the gamified variant included an additional narrative, graphical theme, scoring system with visual and emotional feedback, and the presence of a companion character. In both tasks, food and neutral low-poly stimuli were classified based on their color tone (go trials), but responses were withheld in 25% of the trials (stop trials). Mean go reaction times and stop-signal reaction times (SSRT) were analyzed as measures of performance and inhibitory control.

Results: Participants in the gamified SST had longer reaction times (803 [SD 179] ms vs 607 [SD 90] ms) and worse inhibitory control (SSRT 383 [SD 109] ms vs 297 [SD 45] ms). The association of BMI with inhibitory control was relatively small (r=.155, 95% CI .013-.290). Overweight participants had longer reaction times (752 [SD 217] ms vs 672 [SD 137] ms) and SSRTs (363 [SD 116] ms vs 326 [SD 77] ms). Gamification did not interact with the effect of overweight on mean performance or inhibitory control. There were no effects of gamification on mood and user experience, despite a negative effect on perceived efficiency.

Conclusions: The detrimental effects of heightened BMI on inhibitory control were preserved in a gamified version of the SST. Overall, the effects of overweight were smaller than in previously published web-based and laboratory studies. Gamification elements can impact behavioral performance, but gamified tasks can still assess inhibitory control deficits. Although our results are promising, according validations may differ for other types of behavior, gamification, and health variables.

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KEYWORDS

gamification; inhibitory control; response inhibition; overweight; BMI; stop-signal task; mental health; games; overweight

Introduction

Overweight and obesity are monumental health problems with dramatic increases in prevalence over the past centuries. A heightened BMI encompasses substantial risks for the onset of additional high-risk health conditions such as hypertension, diabetes, and cardiovascular diseases [1]. Next to complex genetic, biological, and environmental factors, and their interactions [2], a core behavioral phenomenon contributing to dysregulated energy balance in overweight is the degree of ability to control impulsive behaviors. Given the attractive value of particularly high-calorie food and its omnipresence in Western obesogenic environments, deficits in inhibitory control have been attributed as prominent factors for etiology and maintenance of energy imbalance behavior [3,4].

The stop-signal task (SST) is a hallmark adaptive paradigm for assessing inhibitory control that has been used extensively in basic research with healthy, overweight, and patient populations. The SST is a cognitive task that requires participants to cancel behavioral responses in a minority of trials after the presentation of a stop-signal, which is delayed according to a performance-contingent time interval. Inhibitory control deficits in this task have been identified in overweight and obese populations [3,4], overweight children [5], and patients with binge-eating disorder [6]. For instance, in the web-based study by Houben et al [4], participants with a BMI of 25 kg/m² or more had longer stop-signal reaction times (SSRTs) in an SST with food stimuli compared with normal-weight participants, which indicates weaker inhibitory control. Meta-analytic results suggested an underlying inhibitory control deficit in overweight and obese persons regardless of bingeing [3]. Accordingly, the SST has also been explored as a training to improve inhibitory control capacities and motivation to engage inhibitory control in critical situations, with the overall aim to provide a rehabilitative or even preventive instrument [7,8]. Initial results from laboratory studies were promising and demonstrated the possibility of weight loss following inhibitory control training [9-13], but long-term results of prolonged interventions are still outstanding [7,14].

Such cognitive tasks or trainings—behavioral tests that measure an underlying cognitive function such as inhibitory control, working memory, or cognitive control—are usually considered to be effortful, repetitive, or even frustrating [15]. Accordingly, these negative affective states might lead participants to disengage or terminate the training activity altogether [16]. Variation of the design elements employed in an SST could improve motivation and training outcomes particularly in upcoming long-term studies comprising multiple sessions. In fact, results of previous studies employing game elements in cognitive trainings indicated positive effects on performance and motivation in clinical [17] and healthy populations [15,18]. Consequently, the so-called gamification [19] of cognitive trainings has increased substantially in recent years [20]. From early on, gamification has been defined as “the use of game design elements in non-game contexts” [19]. Accordingly, gamification elements are a heterogeneous group of design elements covering the graphical presentation of a task, its fictional embedding, performance-contingent feedback, social elements, and other dimensions. By adding game elements to a nongame context, a more enjoyable, exciting, and compelling user experience is contemplated. Some of the most frequent gamification elements are a narrative, occasionally along with a social setting (eg, companion character), a graphical theme, and a scoring system with visual and emotional feedback [21,22].

Two previous studies tested assessments with gamified versions of the SST. In a web-based experiment, Lumsden et al [23] investigated whether scores or a theme environment would affect performance in the SST. However, no effects of gamified variants on attrition rates in an online sample were observed and SSRTs were overall comparable for all variants [23]. Moreover, participants rated the task version with scores as more enjoyable than a plain version and a theme version [23]. A second, more recent study implemented the SST in an endless runner scenario and found comparable performance in both task variants [24]. From these results, it was concluded that web-based gamified versions of the SST can be a potential advancement to applications in mental health. However, neither study investigated the assessment of inhibitory control deficits with a gamified SST in an overweight population.

In this study, we investigated whether the effects of overweight on inhibitory control would be preserved in a gamified SST. In order to gather the most sensitive results, we created 2 maximally contrasting conditions of the same underlying SST. When changing aesthetic and incidental task elements without varying the core mechanics, behavioral performance can still be affected due to higher distraction and motivation, which might affect assessments in different populations. For instance, inclusion of a scoring system in a working memory training negatively impacted performance [25], and use of visually more complex stimuli might affect the psychometric properties of behavioral assessments in game-like environments [26]. If a gamified version of an SST is intended to address inhibitory control deficits in overweight populations, an important requirement would be that the effect of overweight is still present in the altered assessment setting. Technically, comparable effects of BMI on SSRT would indicate external validity of the gamified task. To address this question, we developed 2 versions of an SST comprising food and control stimuli, and we tested whether the effects of overweight on SSRT were present in randomized groups of online testers with varying BMI who were randomly assigned to the gamified or nongamified version of our task. According to the results of Houben et al [4] and the meta-analysis by Lavagnino et al [3], we predicted higher SSRTs for overweight participants in a neutral environment but also in a gamified environment with the identical adaptive SST in both versions.

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Methods

Participants

A total of 111 participants were recruited for the study. A priori, we determined the sample size in a power analysis. For reproducing a positive medium-sized association between inhibitory control and overweight ($r \approx 0.35$; based on the online study of Houben et al [4]), at least 49 participants were required in each group ($\alpha = .05$; $1–\beta = 0.8$; 1-sided). An additional dropout rate of 10% was considered. Participants were randomly assigned to the groups (gamified, nongamified), and demographic characteristics are reported in the results section (age, gender, handedness, BMI, eating pathology). According to the high prevalence of overweight and obesity in the general adult population, we expected about 39% of our participants to be overweight. Participants were required to complete the study on a desktop computer, to be registered on the Prolific platform, and to be older than 18 years; there were no additional screening criteria selected.

The experiment was approved by the local ethics committee of the Leibniz Institut für Wissensmedien, Tübingen (LEK 2020-023). All complete submissions passed the fair attention check items implemented in the beginning and end of the study (see questionnaires). Recruitment used the Prolific platform, and all complete and valid submissions were reimbursed for study participation (3.60 £ [ca. US $5]; 72% of all submissions were valid; 5% of invalid submissions were rejected following the Prolific guidelines; 23% were returned or timed out by participants). The study took approximately 30 minutes.

Gamified and Nongamified SST

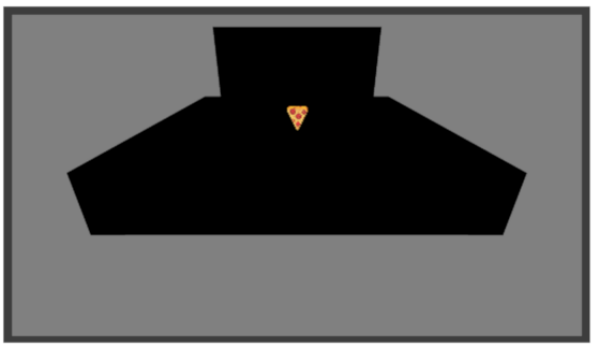
A gamified and nongamified version of the adaptive SST were newly developed for the purpose of this study (Figures 1 and 2). For reliable online assessment of behavioral responses, the task was implemented using the JavaScript library processing.js [27], along with additional code elements from jsPsych 6.0.4 for questionnaires. On the server side, the experiment was controlled with the JATOS framework [28], a Java environment that allows recording data, starting experimental modules, and creating links for participants to run the experiment. The experiment was run and data were stored on a server at the author's institution in Tübingen, Germany.

The gamified and nongamified SSTs were identical with regard to the task procedure. In order to maximize possible effects, the gamified SST additionally included a narrative and graphical theme, scoring system with visual and emotional feedback, and a companion character. These additional gamification elements are described in detail in the next section.

We adhered to the recent consensus recommendations for designing and reporting SST performance [29]. Participants performed a 2-alternative forced choice task, where they had to discriminate objects based on their color. Participants were instructed to press a left or right key (A or L) as fast as possible in go trials but cancel their response in stop trials. We used a bold and salient stop-signal, realized in terms of a red color cue that covered over 25% of the 960×540 screen. In order to avoid waiting strategies and in line with the recommendations, only 25% of the trials were stop trials. Following Verbruggen et al [29], we used an adaptive tracking procedure to adapt stop-signal delays (SSDs). The initial SSD for all participants was set to 200 ms. In cases where participants responded incorrectly in stop trials—including premature responses—the SSD was decreased by 50 ms, down to a minimum of 50 ms. In cases of successful stop trials, the SSD was increased by 50 ms up to a maximum of 900 ms. We also instructed participants explicitly not to wait. The exact wording was "You must not wait for the color change [the stop-signal], otherwise your response times are very long." Participants could familiarize themselves with the procedure in training trials; however, we did not provide blockwise feedback. This was due to the fact that we conducted an online study and tried to keep the experiment as short as possible, with only one single block (and self-paced breaks). In the main experiment, participants performed 256 trials, and 64 of them were stop trials. According to the computational models from Verbruggen et al [29], 50 stop trials should suffice to obtain unbiased stop-signal reaction times (SSRTs).

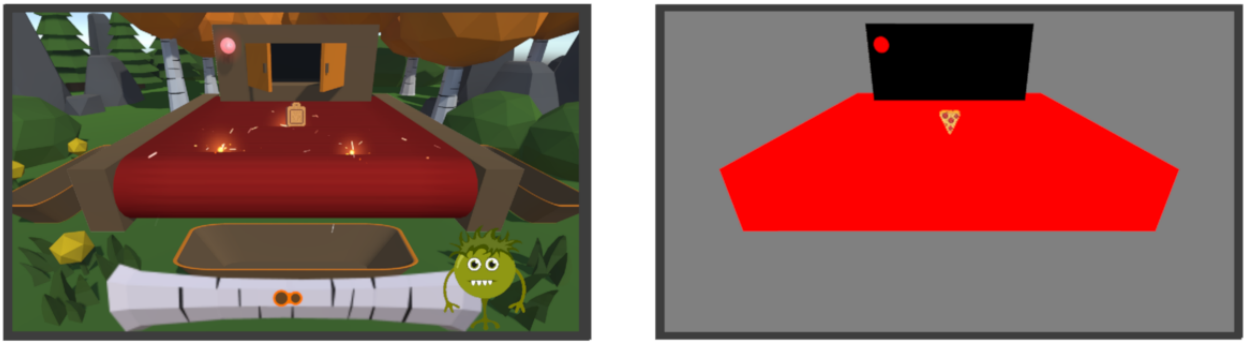
Figure 1. Left: The gamified environment. Stimuli appeared from the warehouse gate at the top of the conveyor belt and subsequently moved down the conveyor belt. The score bar and the companion character, Fred, are visible at the bottom of the conveyor belt. In case of correct responses, the score marker moved to the right; in case of wrong responses, the score marker moved to the left. Right: The nongamified environment. Only the stimuli remain the same as in the gamified version. A black shape covers the area covered by the conveyor belt and the warehouse gate. The forest environment is replaced by a grey background.





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Figure 2. Left: Stop trials in the gamified version. After the stop-signal delay, the light at the warehouse gate and the conveyor belt turned red. Furthermore, the conveyor belt emitted sparks, resembling a short circuit. Right: Stop trials in the nongamified version. The area covered in red matches the location but is slightly larger than in the gamified version. Participants were requested to wait without responding until the end of the trial.



Gamification Elements

The gamified SST was developed in a low-poly graphical style. This design was chosen for two reasons. First, it is considered aesthetical particularly in game-like environments and resembles the style of previous gamified versions of the SST [11,24]. Second, due to its popularity in game design, a lot of free assets are available, like the low-poly nature assets used here.

The displayed environment resembled a forest glade surrounded by trees and rocks. A conveyor belt was in the center of the glade. On top of the conveyor belt, a warehouse gate with a light bulb on the left side was shown (see Figure 1, left panel). At the beginning of each trial, the gate opened, the light bulb turned green, and a stimulus spawned at the top of the conveyor belt. Stimuli traveled down the conveyor belt (this animation was shown in both versions) until participants pressed the left or right key. In this case, the stimulus flew to 1 of 2 bins beside the conveyor belt (only in the gamified version). If participants did not respond, the stimulus fell into a bin at the end of the conveyor belt. When landing in a bin, the stimulus disappeared and a sparkling effect was presented. A trial ended when the stimulus landed in either one of the bins.

During go trials, the light bulb stayed green during the whole trial. In stop trials, the light bulb and conveyor belt turned red (this animation was shown in both versions) Furthermore, the conveyor belt emitted sparks, resembling a short circuit (see Figure 2, left panel, shown only in the gamified version). In this case, participants should not respond at all but should wait until the stimulus fell off the conveyor belt.

Below the conveyor belt, a score bar was displayed on top of a wood log. In case of correct responses, the score indicator moved to the right, in case of wrong answers or responses during stop trials, the bar moved to the left.

To the right of the bar a cartoon figure (Fred) was shown, whose facial expression depended on the score (ie, the figure showed a neutral expression for scores between 25% and 75%, a sad expression for scores below 25%, and a happy expression for scores above 75%). The cartoon figure was also used to provide a narrative theme for the experiment. Participants were requested to help the color-blind Fred operate the conveyor belt by sorting red objects to one bin and brown objects to the other. Stop trials were introduced by mentioning that the conveyor malfunctions sometimes, and participants should not respond in these cases. Participants were also encouraged not to wait for a malfunction, as Fred would not be productive enough in this case.

To sum up the gamification elements, we used a scoring system with visual and emotional feedback, a brief narrative, and appropriate graphics. For the nongamified SST, all elements were removed and only the stimuli remained the same. Instead of the forest glade, participants saw a monochrome grey background. The warehouse gate and conveyor belt were replaced with black shapes covering the very same area. The light bulb remained as a colored circle, which stayed green in go trials and turned red in stop trials. The black shape covering the area corresponding to the conveyor belt in the gamified SST turned red in stop trials. There were no bins, no animations, and no score bar in the nongamified SST (see Figure 1, right panel and Figure 2, right panel).

Stimuli

Participants solved a color decision task in go trials, pressing 1 of 2 defined buttons (A or L) for red or brown targets. The stimuli were selected to match the low-poly environment and consisted of pictograms of high-calorie food (donut, pizza, cake, French fries) or approximately color- and tone-matched nonfood kitchen objects (glove, scissors, wooden hammer, chopping board; see Figure 3). Accordingly, in order to create an overall consistent ambience in the game condition, no realistic pictures were used as these might break with the virtual character and remainder of the visuals shown. Target presentation within the SST was randomized. The factor stimulus type was included in our analysis, because previous studies observed effects of overweight only in blocks of food stimuli [4].

Figure 3. The stimuli. Left: 4 red targets—French fries, glove, scissors, and pizza. Right: 4 brown targets—wooden hammer, cake, chopping board, and donut. Pixel art stimuli were selected for their low-poly, 8-bit style. Stimuli were created by artist VectorPixelStar [30] and used in agreement with the artist in this study.



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Questionnaires

Positive and Negative Affect Schedule

To assess participants' affective states, the Positive and Negative Affect Schedule (PANAS) was employed [31,32]. Both positive (PA) and negative affect (NA) are measured by 10 items. Participants must indicate how they are feeling at the moment by rating items on a Likert scale from 1 (very slightly or not at all) to 5 (extremely).

User Experience Questionnaire

The User Experience Questionnaire (UEQ) [33] was used to assess participant user experience. The questionnaire uses bipolar ratings from 1 to 7 (eg, not interesting to interesting) and evaluates general attractivity, as well as *hedonic quality* (stimulation, novelty) and *pragmatic quality* (efficiency, perspicuity, dependability) of the software.

Game Preferences Questionnaire

The Game Preferences Questionnaire (GPQ) [34] includes 1 item to assess gaming frequency on a Likert scale from 1 (never) to 7 (daily). Further, 9 items are used to measure preferences for certain video game genres (eg, first person shooter, strategy games, adventure games) on a 7-point Likert scale from 1 (strongly dislike) to 7 (strongly like).

Dutch Eating Behavior Questionnaire

The Dutch Eating Behavior Questionnaire (DEBQ) was used to evaluate general eating pathology [35]. The DEBQ consists of 33 items regarding eating behavior and eating-related cognitions, which are divided into restrained eating, emotional eating, and external eating items.

Hunger Visual Analog Scale

A single item asked participants for their current hunger state before the task was started (ie, "How hungry are you in this moment?"). Participants moved a slider between the anchors not hungry and very hungry in response.

Attention Checks

Several fair attention checks items [36] were distributed across the scales before and after the SST. In total, dependent on the question length, there were 6 items such as "To show that you pay attention, please write 2020 in the field below" (eg, as open text field), "To show that you pay attention, please select 'very often' here" (eg, as an item within the DEBQ with the options "never," "seldom," "sometimes," "often," and "very often") or "click 'extremely' please" (eg, as an item within the PANAS with a Likert scale from 1 [very slightly or not at all] to 5 [extremely]). The aim of these items was to confirm that participants actively read instructions and questions, thus ensuring data quality. All fair attention checks were passed by the included study participants in both groups. None of the full study submissions needed to be excluded based on these items.

Additional Questionnaires

For exploratory purposes, we also collected responses on the Body Shape Questionnaire [37] and an adapted version of the Implicit Theories of Intelligence Scale [38]. However, as these constructs were not relevant for answering the research questions of this study, analyses using these questionnaires are not reported here.

General Procedure

Participants were randomly assigned to the gamified or nongamified SST. Beside the task, both groups completed several questionnaires. Before starting the study, participants completed a captcha by drawing a certain path. Next they received general information about the procedure of the study; after this, they were asked to provide their year of birth and complete a PANAS questionnaire. This was followed by the first attention check and instructions for the SST. Participants then completed the gamified or nongamified SST. After this, participants were requested to complete several questionnaires, starting with a second PANAS and a UEQ. This was followed by demographic data (age, gender, handedness, BMI, eating pathology), a second attention check, GPQ, DEBQ, body shape questionnaire, and implicit intelligence questionnaire.

Data Treatment and Statistical Analysis

Out of the approved submissions with correctly answered attention checks, data inspection revealed 1 additional submission without behavioral data (failed recording of reaction times) and 3 submissions with self-reported height below the 95% confidence interval of human height [39], which could not be considered for calculation of BMI effects. These submissions were reimbursed but not further considered for analyses. Next, the prerequisites for the estimation of SSRT were evaluated [29]. Responses of 7 participants were excluded because stopping probabilities were outside of the interquartile interval (25% to 75%) in 1 or 2 conditions. Moreover, latencies in stop trials were longer than latencies in go trials for 11 participants. In line with the recommendation of Verbruggen et al [29], these values were rejected from the analyses as the assumption of an independent race model was violated.

For investigation of mean reaction times, only responses from go trials were considered. Mean reaction times were aggregated individually and separately for food and neutral stimuli. For investigation of inhibitory control, the SSRT was calculated following the integration method with replacement of go omissions [29]. Since the time for canceling a response cannot be measured directly, this approach considers the individual stopping probability to determine mean reaction time. Next the mean SSD was calculated for every condition and subtracted from reaction time (SSRT = RT[go|pStop] – mean[SSD]). This procedure yields the most reliable SSRT estimate [29]. In the task, SSD was adjusted separately for food and neutral stimuli; accordingly, both SSRT measures could be calculated.

To account for the imbalanced data set resulting from the data cleaning, we used linear mixed effects modeling for the analyses [40]. All analyses were performed in R version 4.0.3 (R Foundation for Statistical Computing) [41], using the nlme package [42]. Subjects were modeled as random effects, with *stimulus* (food vs control) as repeated measures fixed effects and *overweight* (low vs high) and *group* (gamified vs nongamified) as between subjects fixed effects. In line with Houben et al [4], overweight status was operationalized as BMI ≥25 kg/m², which led to comparable proportions of

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approximately 30% overweight and obese participants in both groups (see Table 1). Moreover, age was entered as a continuous variable to the models following the significant age difference between the gamified and nongamified group. To quantify effect sizes with continuous variables, product-moment correlation coefficients were calculated.

Results

User Statistics

The groups were comparable in a number of demographic variables (Table 1, Multimedia Appendix 1). Importantly, there were neither significant differences in BMI nor general eating pathology according to the DEBQ. However, a significant age difference was observed ($t_{78.47}$=2.29, *P*=.02) with slightly older age in the game group (29.6 [SD 11.3] years) than in the no-game group (25.3 [SD 7.2] years). To control for age differences in behavioral scores, particularly regarding inhibitory control, age was entered as covariate to the subsequent models.

Gaming frequency was moderate in both groups (see Table 1). Following the suggested use recommendation of the GPQ [34], participants were classified into 4 groups of gamers (casual = 16, well-rounded = 9, hardcore = 28, no-gamer = 47). That is, about half of the participants can be considered to be no-gamers.

Table 1. User statistics for the gamified and nongamified group.

Characteristic	Gamified (n=48)	Nongamified (n=52)
Overweight, n (%)	15 (31)	15 (29)
BMI, normal weight, mean (SD)	21.42 (1.92)	21.14 (2.61)
BMI, overweight, mean (SD)	29.28 (3.11)	27.97 (4.05)
State hunger, mean (SD)	37.85 (31.62)	38.46 (31.63)
DEBQ[a] restrained, mean (SD)	16.96 (8.83)	17.08 (9.74)
DEBQ emotional, mean (SD)	20.90 (12.39)	20.38 (12.93)
DEBQ external, mean (SD)	22.63 (5.71)	23.54 (6.24)
Female [other], n (%)	22 (46) [0 (0)]	18 (37) [2 (4)]
Left-handed, n (%)	5 (10)	8 (15)
Age in years, mean (SD)	29.6 (11.3)	25.3 (7.2)
Gaming frequency, mean (SD)	3.23 (2.12)	3.17 (1.98)

[a]DEBQ: Dutch Eating Behavior Questionnaire.

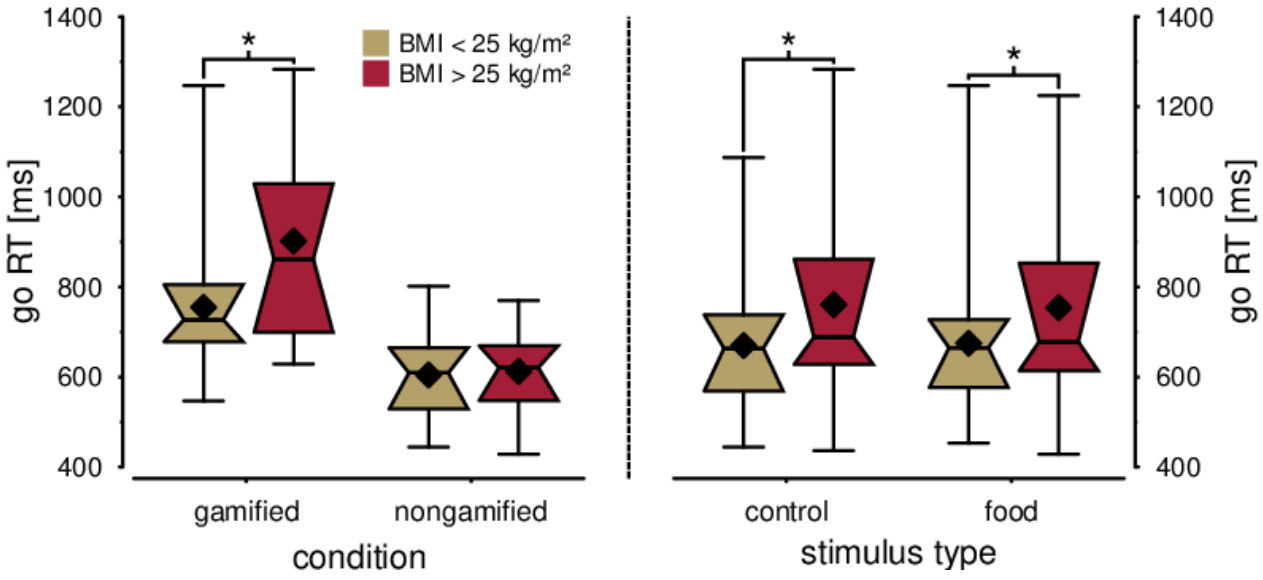
Reaction Times

For mean reaction times in go trials, the covariate *age* was not significant ($F_{1,95}$=0.12, *P*=.74). The main effects of *condition* ($F_{1,95}$=48.87, *P*<.001) and *overweight* ($F_{1,85}$=6.63, *P*=.01) were statistically significant. Moreover, there were significant 2-way interactions between *overweight* and *condition* ($F_{1,85}$=3.98, *P*=.049), as well as between *overweight* and *stimulus* ($F_{1,87}$=4.40, *P*=.04).

Figure 4 illustrates these interactions. Longer mean reactions were particularly pronounced in overweight participants in the game condition ($F_{1,45}$=5.79, *P*=.02), but not in the nongamified condition ($F_{1,45}$=0.26, *P*=.61; Figure 1, left panel). Moreover, prolonged responses of overweight participants were particularly pronounced for control stimuli ($F_{1,90}$=9.73, *P*=.002), but the difference between groups was still significant for food stimuli ($F_{1,91}$=6.92, *P*=.01). Further interaction terms or the stimulus main effect were not statistically significant (*F*s<1.23, *P*s>.27).

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Figure 4. Effects of gamified versus nongamified stop-signal task and control versus food stimulus type on mean reaction times in go-trials. Longer reaction times of the overweight group were observed in the gamified stop-signal task but not in the nongamified stop-signal task. This effect was slightly larger for control stimuli; there was no significant stimulus difference within or across groups. RT: reaction time.

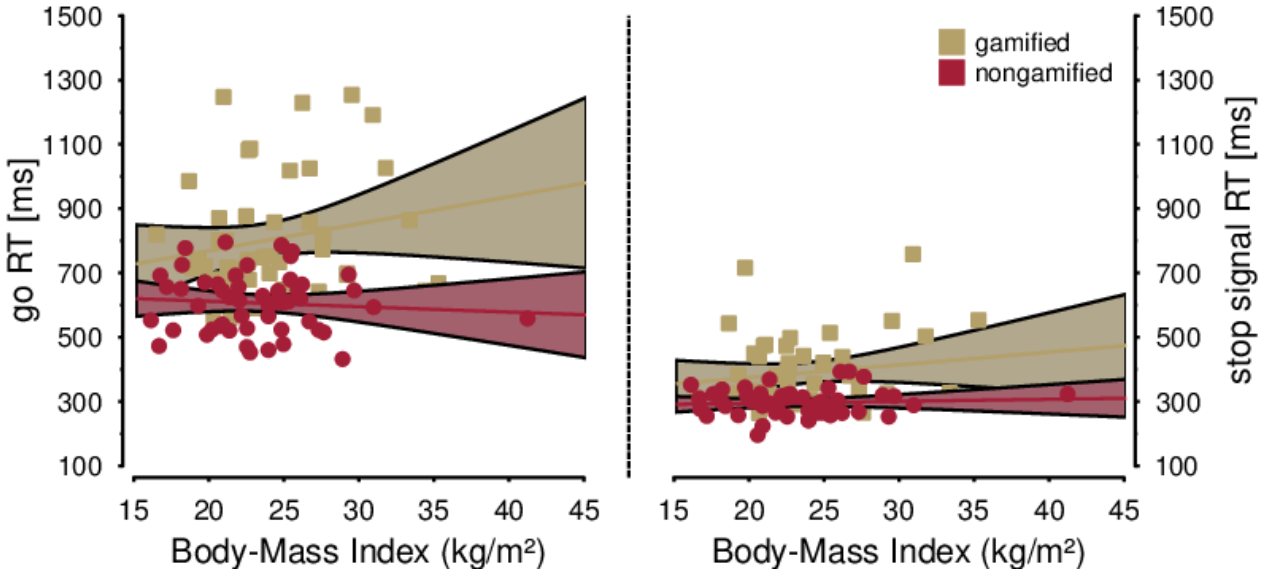


SSRTs

For SSRTs, the covariate *age* was statistically significant ($F_{1,95}$=4.93, *P*=.03), and SSRTs increased with older age (r_{189}=0.25, *P*<.001). Moreover, there was a significant main effect of *condition* ($F_{1,95}$=33.83, *P*<.001), indicating longer SSRTs in the gamified condition (383 [SD 115] ms) compared with the nongamified condition (294 [SD 48] ms). In line with our prediction, a trend was observed for the main effect *overweight* ($F_{1,95}$=3.39, *P*=.07), driven by slightly longer SSRTs in overweight participants (361 [SD 123] ms) compared with normal weight participants (328 [SD 84] ms).

Most importantly, *overweight* was not further qualified by an interaction with the factor *condition* ($F_{1,95}$=0.16, *P*=.69) nor by any other 2- or 3-way interaction (*F*s<1.17, *P*s>.28). Across the entire sample, SSRTs increased with BMI (r_{189}=.155, *P*=.03). Notably, the effect size was substantially smaller than in previous research (see Figure 5, right panel).

Figure 5. Scatter plots of BMI as a predictor for go reaction time (left) and stop-signal reaction time (right). The gamified versus nongamified condition qualified the association with mean go reaction time but not with stop-signal reaction time. RT: reaction time.



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As a sensitivity analysis, we also calculated the correlation coefficient after exclusion of outlier values, as indicated by visual inspection of the scatter plot (Figure 5). Six values were identified as outliers. The magnitude and significance of the overall associations did not change substantially (r_{183}=.162, *P*=.03).

Effects on Mood and User Experience

Both positive and negative affect decreased from pre-SST to post-SST in both conditions ($F_{1,98}$=23.74, *P*<.001), but there was neither an interaction with valence (*F*s<1.97, *P*s>.17) nor any interaction with the gamified or nongamified condition (*F*s<1.40, *P*s>.24). In the post assessment of the task with the user experience questionnaire, no significant differences were observed for attractiveness, perspicuity, dependability, stimulation, or novelty (*t*s<1.52, *P*s>.15). The efficiency score of the gamified SST (11.41 [SD 2.62]) was significantly lower than the nongamified SST (12.60 [SD 1.97]; $t_{87.01}$=–2.52, *P*=.01).

Discussion

Principal Findings

This study investigated the effects of game elements in an SST in participants with and without overweight. Our primary aim was to investigate whether inhibitory control deficits were preserved in a gamified SST. We observed worse performance and inhibitory control in overweight participants, and effects of overweight were preserved or even enhanced in the game variant of the SST. Overall, these results indicated that a gamified SST can be used to assess inhibitory control deficits in overweight populations, and we replicated effects of overweight on inhibitory control. This suggests the external validity of using a gamified version of the SST.

Results of this study showed that the gamified SST was more difficult than a more conventional version of the SST without game elements as reflected by higher go reaction times, which was particularly apparent in overweight participants. The additional game elements in the gamified version of the SST might have distracted participants and increased participants' cognitive load, which resulted in longer reaction times. This seems to be in line with research on so-called seductive details—interesting but irrelevant elements for achieving a task's objectives. As such, research in the field of seductive details showed that, for instance, adding pictures to learning material such as textbooks that are not strictly relevant for achieving the instructional goal but rather should make the learning material more interesting can lead to poorer performance (for a review see Rey [43]). In this case, for instance, the additional presence of the character, Fred, with animated feedback might have drawn the attention of participants and slowed their overall performance. Indeed, results of a recent eye-tracking study comparing a gamified with a nongamified task indicate that the game character provided was one of the most frequently fixated game elements [44]. The pattern of results could imply that the gamified task might recruit additional cognitive mixed abilities [26]. Accordingly, it is crucial to investigate the external validity of the measures from the task with other external variables such as weight status (eg, if the task is more complex and distracting, it could be that its outcome measures such as SSRT or mean reaction time would not only reflect a specific cognitive function but are affected by additional involvement). Accordingly, a gamified task could in theory no longer measure deficits in a particular way.

Because multiple game elements like an additional narrative, graphical theme, scoring system with visual and emotional feedback, and a companion character were incorporated in the gamified version of our study, it is not clear which of these elements exactly led to overall longer reaction times. Previous research could potentially indicate that the theme manipulation, which usually includes extensive changes to graphics, might be particularly distracting; in a study comparing points and themes individually, the themes variant of an SST was evaluated as worst but had also descriptively less attrition, paradoxically [23]. That study also showed comparable behavioral results (ie, longer reaction times in a theme vs neutral variant) with slightly smaller effect sizes, suggesting that the additional game elements might have exacerbated the effects on performance in this case. In a separate study, performance was improved by points, but enjoyment suffered in a themed variant of another task [45]. From our results, we can only speculate that the possible motivating effects of a score bar might have been abolished by the presentation of a graphical and narrative theme, but future research is required to investigate the isolated and combined effects of these design elements. Since the goal of our study design was to create maximally contrasting conditions, the general behavioral effects in reaction times confirm that the sum of gamification elements indeed affected performance.

Concerning participants' inhibitory control, SSRTs were slower in the gamified compared with the nongamified version of the SST. This again might indicate an increased perceived cognitive load due to the implemented game elements. Alternatively, it could also be related to the dependence of SSRT on go reaction time distributions. Most importantly, the gamified task condition did not interact with overweight status of the participants, and we observed a slight yet nonsignificant increase in SSRTs with heightened BMI, in the direction of our prediction. This effect was substantiated by a positive association between SSRTs and BMI across task conditions, even though the effect was smaller as in previously published studies [3,4]. Nevertheless, this study replicated inhibitory control deficits in overweight populations, suggesting an underlying cognitive deficit [3,4]. Moreover, the results also demonstrated the heightened difficulty with exerting inhibitory control in visually more complex situations (ie, the use of game elements). Importantly, since associations of SSRTs with BMI in the gamified SST were preserved, we suggest it appears promising to use such settings for future inhibitory control trainings. Besides potential effects of game elements on performance and motivation, a (visually) more rich, naturalistic, or diversified training environment might facilitate transfer effects to inhibitory control behavior, although the available evidence on this hypothesis is still very scarce [7,46]. Food-specific response inhibition deficits are already present in overweight elementary school children [5], and gamified response inhibition trainings could be particularly promising in younger populations.

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Additional interesting observations were obtained in the analysis of go trial reaction times. Beyond the main effect of condition, overweight participants' responses were particularly slower in the gamified SST, whereas there were no significant group differences in go reaction times in the conventional SST. Moreover, the pattern of increased go reaction times in overweight participants was slightly larger for neutral stimuli but still significant for food stimuli. This might reflect higher response (motivational) salience of food cues in overweight participants [47]. However, other studies in a go-/no-go task observed similar trends for faster responses to food cues in both obese and healthy participants [48] or opposite effects of faster responses to neutral cues in a conventional SST [49]. To investigate these inconsistencies in the literature, the exact configurations of tasks, stimuli, and other study design characteristics should be addressed in future studies. Nevertheless, a more straining task using a visually richer and distracting environment, at least compared with the conventional versions of the SST, might be more comparable to inhibitory control requirements in complex and distracting real-life settings [7].

By implementing game elements into the SST, we aimed at increasing mood and user experience of participants. Our analyses, however, showed that in both the gamified and nongamified SST, positive and negative effect decreased from pretest to posttest. Despite the use of supposedly (emotionally) engaging game elements, changes in mood were comparable in both conditions. This is in contrast to previous studies showing that game elements increase positive affect [50] or at least help to prevent positive affect from dropping in strenuous cognitive tasks [15]. Moreover, attractiveness of the task design and hedonistic and (most) pragmatic qualities of user experience were not affected by the used game elements. On the contrary, the gamified SST was rated to be less efficient than the nongamified SST. This might suggest a less than optimal integration of game elements in this experiment. Consequently, the use of game elements in the current implementation did not prevent negative affective effects of performing a cognitive task usually considered to be cognitively challenging. Interestingly, a previous similar theme- and point-based implementation of the SST had equal attrition rates compared with a neutral variant [23]. In sum, these results may suggest that a gamification of this task in an online setting might require further design changes.

Comparison With Prior Work

Previous studies had investigated assessments with a gamified SST [23,24]. Lumsden and colleagues [20] investigated whether scores or a theme would affect attrition rates and performance in a web-based SST across multiple sessions of testing. Compared with a neutral version of the SST, no differences were observed regarding attrition, which suggests similar motivation of participants. In their study, points affected users' engagement positively in the subjective evaluations. Regarding inhibitory control, SSRTs in the theme variants of their SST were higher than SSRTs in the point variant (but statistically not different from the neutral variant; see Figure 12 in Lumsden et al [23]), which appears to be consistent with our results. Moreover, their study also showed higher mean reaction times in the theme condition compared with the neutral variant (supplementary material in Lumsden et al [23]).

More recently, Friehs and colleagues [24] designed and developed a more sophisticated version of the SST by using an endless runner scenario in a 3D virtual environment. While participants performed similarly in both the gamified and nongamified versions, the gamified version led to higher enjoyment and flow. This might indicate that more substantial changes to the SST, as realized by Friehs and colleagues [24], are necessary to change participants' affective states. Contrary to our results, there were no performance differences between the task versions [24].

Moreover, whereas some previous studies observed cue-specific effects of food stimuli [3,4,48], the factor stimulus-type was not significant in other experiments [49] or in our study. We consider various potential factors of interest for further investigation: (1) our low-poly stimuli may have been too abstract (as opposed to photographs of real food), (2) both stimulus types appeared in the same SST blocks, with separate calculation of SSRT (but see Svaldi et al [6]), (3) the stimulus category was not task relevant, and (4) the control category was topically related to food cues. For training studies, cue-specific stimuli appear to be highly relevant [7].

Limitations

This internet study assessed BMI in self-report, analogous to previous studies [4]. Nevertheless, self-presentation biases might have been evident in both groups. The subjective evaluations of the gamified SST in the UEQ were weak, since mood decreased in both conditions and no differences in user experience were appraised by our study participants. Thus, there is potential for improvements in the user experience of the gamified SST. As outlined by a reviewer, more nuanced and implicit assessments of user enjoyment should be considered in future research (eg, dual tasks or attrition rates [23,51]). However, we found relatively large performance differences in the 2 versions, comparable to the experienced differences in efficiency, with higher values for the no-game task. Since we recruited clickworker for a single assessment study, the potential role of self-motivation in an SST training could not be considered (but see Forman et al [13] and Lumsden et al [23]). Change motivation (eg, concurrent participation in a weight-loss program) and psychoeducation could substantially increase the user experience in future studies.

Participants in this study had no formal diagnosis and we did not control for patterns of binge eating, in line with previous research [4]. General eating pathology in the gamified and nongamified groups was comparable according to the DEBQ [35]. Finally, participants in the gamified SST were significantly older than participants in the conventional SST group.

Conclusions

We observed longer reaction times in the gamified task, particularly in overweight participants, and longer SSRTs. The detrimental effects of heightened BMI on inhibitory control were preserved in a gamified and comparable nongamified version of the SST, as shown in small positive associations of overweight with SSRTs regardless of task version and stimulus

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type. However, mood and user experience were identical in both version; thus, it seems that the design of an enjoyable version of this task remains difficult. Gamification elements can impact behavioral performance but can be used to assess inhibitory control deficits in different populations.

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Comparison of overweight and normal weight groups.
[DOC File , 34 KB - games_v9i1e25063_app1.doc]

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Abbreviations

DEBQ: Dutch Eating Behavior Questionnaire
GPQ: Game Preferences Questionnaire
PANAS: Positive and Negative Affect Schedule
SSD: stop-signal delay
SSRT: stop-signal reaction time
SST: stop-signal task
UEQ: User Experience Questionnaire

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Original Paper

Perception of Game-Based Rehabilitation in Upper Limb Prosthetic Training: Survey of Users and Researchers

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Abstract

Background: Serious games have been investigated for their use in multiple forms of rehabilitation for decades. The rising trend to use games for physical fitness in more recent years has also provided more options and garnered more interest for their use in physical rehabilitation and motor learning. In this study, we report the results of an opinion survey of serious games in upper limb prosthetic training.

Objective: This study investigates and contrasts the expectations and preferences for game-based prosthetic rehabilitation of people with limb difference and researchers.

Methods: Both participant groups answered open and closed questions as well as a questionnaire to assess their user types. The distribution of the user types was compared with a Pearson chi-square test against a sample population. The data were analyzed using the thematic framework method; answers fell within the themes of usability, training, and game design. Researchers shared their views on current challenges and what could be done to tackle these.

Results: A total of 14 people with limb difference and 12 researchers participated in this survey. The open questions resulted in an overview of the different views on prosthetic training games between the groups. The user types of people with limb difference and researchers were both significantly different from the sample population, with χ^2_5=12.3 and χ^2_5=26.5, respectively.

Conclusions: We found that the respondents not only showed a general willingness and tentative optimism toward the topic but also acknowledged hurdles limiting the adoption of these games by both clinics and users. The results indicate a noteworthy difference between researchers and people with limb difference in their game preferences, which could lead to design choices that do not represent the target audience. Furthermore, focus on long-term in-home experiments is expected to shed more light on the validity of games in upper limb prosthetic rehabilitation.

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KEYWORDS

upper limb; rehabilitation; arm prosthesis; serious games; engagement; transfer

Introduction

Background

Serious games have been shown to enhance the outcome of movement rehabilitation after stroke or cerebral palsy [1,2]. Computer games have also been researched for upper limb prosthetic control training since the early 1990s [3-14]. Although the field has received considerable attention over recent years, it has yet to succeed in finding general proof for successful transfer of training myoelectric control in the games to an increase in prosthetic control ability [15]. For instance, transfer has only been found in training a strongly activities of daily living (ADL)–relevant task in a virtual environment [15].

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The skills required to play a game can be learned with practice. A serious game incorporating training exercises consistent with a rehabilitation regimen allows the numerous repetitions of exercises necessary during rehabilitation therapy to take place. Nonetheless, it is hypothesized that the training needs to be engaging to ensure regular and consistent adherence to the exercises [12,16]. Current prosthetic training games revolve around 2 core themes: the engagement of the player [7,8,12,14,16-20] and the skill transfer from the game to prosthetic use [15,20,21]. These 2 objectives are pursued with 2 types of video games that aim to improve myoelectric control (*myo-games)* [10] in prosthetic training: (1) games that are based on existing game platforms with input adjusted to the electromyogram (EMG) signals [4,6] and (2) completely novel games around specific training goals [9,20].

Few researchers specifically acknowledge the importance of considering the diversity of the target audience when developing games in general [16,17,22,23] and, therefore, myo-games specifically. Even fewer researchers have attempted to address this difference in preferences in their developed games and take the views of people with limb difference into account before starting the development process. A notable exception is the work of Tabor et al [16], who collected qualitative feedback from a small testing group and incorporated the suggestions into their game design. Owing to the diversity in the population, where people have varying definitions of fun aspects and expectations for games, multiple attempts have been made to categorize people into user types [24-26]. Professional game development is based on the psychology behind those types of gamers and the choice of the appropriate game design elements fitting for the target audience. However, academic game development is typically carried out over a relatively short period and by a small, nonspecialist team, which is in stark contrast to the years of development time often carried out by a large and highly specialized team that goes into modern games. This means that the decision making in these games is potentially subject to the preferences of a small team that does not generally reflect the preferences of the target audience.

Objectives

We hypothesized that there are considerable differences between the views of prosthesis end users and researchers with regard to engaging aspects of a game. To test this hypothesis, we created a survey and sought to determine the focus points of each of these groups. In addition, we included a user type questionnaire to ascertain the distribution of each participant group for comparison. Using such a user type distribution can deliver useful information to lead general design choices in game development. It could also be used for presets that emphasize certain game design elements over others for increased user engagement. Furthermore, this survey aimed to identify other challenges than potential disparities in game preferences that the community of researchers could have to face on the path of game-based upper limb prosthetic rehabilitation. This study adds the opinions of researchers and people with limb difference about games in upper limb rehabilitation to the research that has been conducted on the opinions of clinicians [27].

Methods

Study Design

The study was approved by the University Ethics Committee of Newcastle University under the reference number 905/2020. The survey was conducted from February 2020 to May 2020. Participants were either people with upper limb difference or researchers who were active in the research of games for prosthetic training or in prosthetic research in general. All participants gave their consent by filling out and submitting the survey as stipulated on the first page of the survey form.

The recruitment of this study was conducted predominantly on the web via personal contacts. Additional outreach was done via social media and by contacting charities in the United Kingdom that are involved with people with limb difference. Specifically, the survey was sent out to the main and local branches of 13 different charities as well as 40 researchers involved in upper limb prosthetic research. The inclusion criterion for people with limb difference was the absence of the upper limb, irrespective of level, side (unilateral or bilateral), or use of a prosthesis. A total of 14 people with limb difference and 12 researchers filled out the survey. An overview of the demographic data of the participants is presented in Tables 1 and 2. We chose a web-based survey and expected that the web-based nature would increase the number of people willing to participate because of ease of access. In addition, the web-based survey offered the participants time to think about their answers without the pressure of coming up with an answer on the spot. The survey was developed in English and was not altered over the course of the study. The participants were given the option to contact the authors if they did not want or were not able to fill out the survey on the web. No participant used this option.

The survey first introduced the general aim of the study and the contact information of the first and the last author and the Data Protection Officer of Newcastle University. The survey asked for general demographics and, in case of people with limb difference, for anamnesis with regard to their limb. This was followed by a user type questionnaire originally developed by Tondello et al [26]. The survey concluded with open questions about the preferences and opinions of participants with regard to games in general and games in prosthetic training specifically. The researchers were asked to answer additional questions concerning the challenges in this field of research.

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Table 1. Participants' demographics.

Gender	Age group (years)	Type of limb difference	Side of limb difference	Level of limb difference	Prosthesis use	Former participation in research
F[a]	31-40	A[b]	Dominant	Above elbow	No, but interested	Yes
M[c]	31-40	C[d]	Dominant	Below elbow	Former	No
F	41-50	A	Both	Below elbow	Tried	No
F	41-50	A	Nondominant	At shoulder	No, but interested	No
M	41-50	C	Nondominant	Below elbow	Active	Yes
F	41-50	A	Dominant	Below elbow	No, but interested	No
M	41-50	C	Nondominant	Below elbow	Active	No
F	41-50	A	Dominant	Above elbow	Tried	Yes
M	51-60	A	Dominant	Below elbow	Active	Yes
F	51-60	A	Dominant	Below elbow	No, but interested	Yes
F	51-60	C	Nondominant	At wrist	No, no interest	Yes
M	51-60	C	Nondominant	Below elbow	Active	Yes
M	51-60	A	Dominant	Below elbow	No, but interested	No
M	61-70	A	Nondominant	Below elbow	Active	No

[a]F: female.

[b]A: amputation.

[c]M: male.

[d]C: congenital.

Table 2. Researchers' demographics.

Gender	Age group (years)	Profession
M[a]	20-30	Researcher
M	31-40	PI[b]
M	31-40	Medical doctor
M	31-40	PI
M	31-40	PI
M	41-50	PI
M	41-50	PI
M	41-50	PI
M	41-50	PI
M	41-50	PI
Undisclosed	Undisclosed	PI
Undisclosed	Undisclosed	Undisclosed

[a]M: male.

[b]PI: principal investigator.

Data Analysis

The results of the user type questionnaire were processed using MATLAB (The MathWorks, Inc). A goodness-of-fit test using the Pearson chi-square test with a significance level of α=.05 was conducted for both participant groups, compared with the distribution published by Tondello et al [26]. This test was chosen to identify potential differences between the distribution of user types of the participant groups and the distribution of a larger sample population.

For the analysis of the resulting data for the open questions of the survey, we applied the thematic framework approach [28]. This approach consists of 5 steps:

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1. Familiarization: All authors familiarized themselves with the collected data. The first author created an initial theme set, which was discussed and agreed upon by all authors.
2. Identifying a thematic framework: The first author created a set of subthemes for the data set. This was approved by the last author for use in the next steps. The full set of themes can be found in Table 3.
3. Indexing: All authors coded the interview data independently. These were discussed between all authors until a consensus was reached.
4. Charting: The data were sorted by themes and subthemes by the first author.
5. Mapping and interpretation: The first author summarized and interpreted the charted data according to the themes.

Table 3. Thematic framework.

Themes	People with limb difference (n=39), n (%)	Researchers (n=108), n (%)
Usability	*6 (15.4)* [a]	*11 (10.2)*
Accessibility	4 (10.3)	4 (3.7)
Data management	0 (0)	2 (1.8)
Hardware	2 (5.1)	5 (4.6)
Training	*14 (35.9)*	*38 (35.2)*
Muscle development and control	4 (10.3)	4 (3.7)
Prosthetic ability	7 (17.9)	15 (13.9)
Additional benefits for users	2 (5.1)	8 (7.4)
Clinical and research benefits	1 (2.6)	4 (3.7)
Education	0 (0)	4 (3.7)
Feedback	0 (0)	3 (2.8)
Game	*19 (48.7)*	*32 (29.6)*
Affect	5 (12.8)	17 (15.7)
Personalization	3 (7.7)	7 (6.5)
Social aspects	0 (0)	1 (0.9)
Mechanics	11 (28.2)	7 (6.5)
Challenges	— [b]	*27 (25.0)*
Justification and reasoning	—	11 (10.2)
Design and development	—	10 (9.3)
Involvement	—	2 (1.8)
Recognition	—	4 (3.7)

[a]Italicized values denote the subtotals for the respective main themes.

[b]—: Not available. People with limb difference were not asked about research-specific challenges.

Results

General

A total of 14 people with limb difference and 12 researchers in the prosthetic field participated in the survey (Tables 1 and 2, respectively). Of the 14 people with limb differences, 7 had experience with studies pertaining to rehabilitation with a computer-based device before the survey.

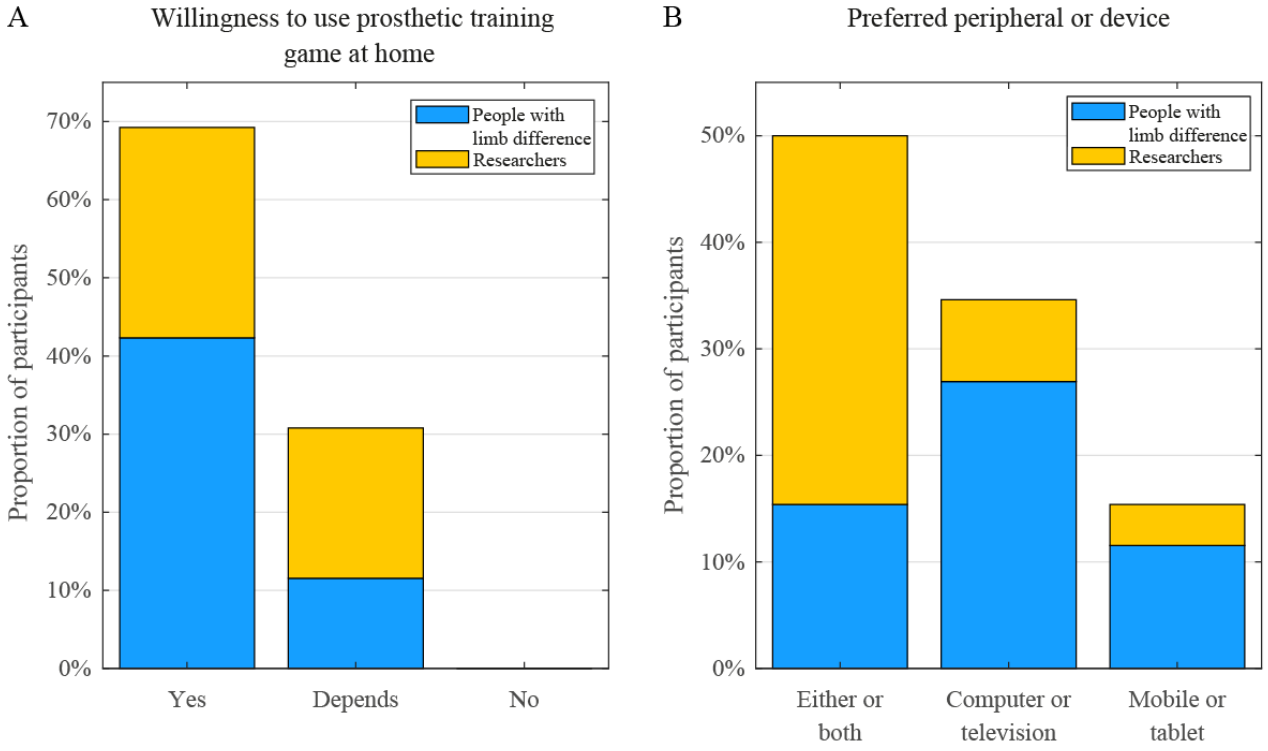
An overview of the themes identified from the survey data is presented in Table 3. In the following sections, the responses of the survey participants are presented. The texts in *italic* font are direct quotes from the participants. The results are reported thematically: usability, training, game design, and challenges. The raw survey results are provided in Multimedia Appendix 1.

Usability

The majority of the participants, both people with limb difference and researchers, indicated that they believed that people in prosthetic training would use game-based training at home (Figure 1). A total of 3 of the 14 people with limb difference and 5 of the 12 researchers cautioned that factors predominately concerning usability and game design can affect adoption, as usability is one of the issues as to why former gamers have stopped playing virtual games:

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Figure 1. Participant response proportions for (A) their willingness to use a game-based prosthetic training tool at their own home and (B) their preferred peripheral or device for such a game.



> *I used to play an Atari, as it had joystick controls, but I struggle with handsets, so [I have] not played for some time.*

In addition, participants pointed out that such a tool should prove easy and robust to use both in setup as well as in the actual use of the tool.

An additional concern was raised with regard to the compatibility of the software with potentially existing hardware at home. One participant said:

> *[Requirements for game-based prosthetic training include] providing a setup that is easy to use and robust; ensuring a game framework that allows people to use their own devices.*

Creating a game framework that would work cross-platform with potentially outdated hardware is a significant challenge for the myoelectric control research community. A step in this direction could be the development of web-based gaming platforms, as mentioned by one of the researchers. Furthermore, researchers have indicated the importance of the exchange of code and knowledge within the community.

The preferred choice of platforms and peripherals, the input and output devices with which the game is played, was more distinct in the case of the participants with limb difference than the researchers. Figure 1 shows that the majority of people with limb difference would prefer a computer or television screen. However, researchers have shown no clear preference for the mobile over fixed screen options.

Training

The topics connected to the main theme of training were grouped into muscle development and control; prosthetic ability; additional benefits for users, clinicians, and research; education; and feedback.

The answers concerning muscle development and control mostly centered on the participants' hopes and expectations. People with limb difference expect the game to help develop the musculature in their remaining limb and improve prosthetic dexterity with these muscles. For instance, a participant with limb difference wished for a game that highlighted the following:

> *my ability to use advanced prosthetics.*

Another participant with limb difference would like to see a game made that also helps to reduce the phenomenon of phantom limb pain.

Researchers additionally specified their hopes in the direction of accelerated learning speeds, the training of ADL-related tasks, and the transfer of the skills learned in the game to prosthesis use. One researcher stated that any tool created should be based on the needs of the patients as well as clinicians. Outside of the physical benefits, researchers pointed out that a game-based tool could allow the user to share data with other users, if they wanted to, and potentially lead to a reduced need for input through in-clinic appointments.

In addition, a training game could support therapists in assessing patients' abilities. One researcher indicated:

> *In the end the games should also relieve the therapists from time spending on rehabilitation. Moreover, the games should be helpful as an assessment tool for the appropriateness of a prosthesis for a given patient.*

The need of personalized feedback for users was raised by a couple of researchers. They envisioned the benefits of regular

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and individualized training progress feedback by which users as well as therapists can track their skill progression properly.

Game Design

The answers of the participants directly relating to design choices for the game were grouped under the main theme of game design. The subtheme of affect included all answers that aimed at an emotional response of the user; personalization contains in-game control of design for the player; social aspects revolve around the possibility of interaction with other players; and answers in the mechanics subtheme pertain to ideas for the mechanical features of the game.

With regard to the affective aspect of the design, participants of both groups indicated that the game had to be engaging for in-home adaption. For instance, one researcher points out that rehabilitation games should not only be interesting in the short term but also be able to secure the long-term engagement of the user. However, engaging the user to a sufficient level was recognized as a challenge.

Furthermore, researchers say that the game should be attractive to users, although it could be hard to appeal to a wide range of potential users. A range of games or in-game options could be beneficial because of the differing motivating factors. The degree of immersion was wished for by a participant with limb difference, and another participant pointed out the potential of an *empowering portrayal of life postamputation* in the game, for example:

> *That the game would be so immersive that the participant would not realise they are training their remnant muscles for optimal EMG based control.*

Interestingly, one participant with limb difference suggested an *end of world* setting. As this might not feel appealing for all users, the setting should be customizable by the player. Some participants from the limb difference group wanted to see a relatable character using a prosthesis in the game, tying in with the empowering effect mentioned earlier. This affords a viable option for personalization:

> *Perhaps the protagonist could be a prosthetic wearer*
> [...]

The variety of preferences in the thematic setting of the game can be seen in Multimedia Appendix 2. These are results of a multiple-choice question and therefore do not add up to 100%.

The mechanics of a game-based prosthetic training tool are predominately addressed with respect to the game genre. Participants of the limb difference group identified a variety of different genres as desirable, including quiz and puzzle games, but also adventure, shooter and fighting games, and horror games. One participant mentioned more specific activities, such as camping, fishing, and shooting. A researcher argued against the use of war and fighting mechanics in clinical settings. The different genre preferences of the participants can be found in Multimedia Appendix 2. As mentioned earlier, these results do not add up to 100%.

An additional influence on the type of game and the game mechanics involved can be the type of gameplay the user prefers. As it cannot be assumed that a user is an active or former gamer and therefore knows what they look for in a game, an assessment of the user types using the Hexad Scale [26] was conducted in this survey. The outcome of this assessment for both people with limb difference and researchers can be seen in Multimedia Appendix 2. Among the people with limb difference, the philanthropist and the achiever user type are tied as clearly the most common types, whereas the player and the disruptor are the least commonly occurring. None of the researchers were grouped into players and disruptors, which is similar to them being the least common type in the other group. We observed a notable difference in the overall distribution of user types to people with limb difference. A Pearson chi-square test was conducted to test the statistical significance of this difference. The results showed that both groups were significantly different from the control group in a study by Tondello et al [26] at a significance level of α=.05. However, the results for the people with limb difference at χ^2_5=12.3 are noticeably closer to the critical value of χ^2_5=11.1 than the result of the researcher participant group of χ^2_5=26.5. This indicates that the group of participants with limb difference showed a higher similarity to the sample population presented in a study by Tondello et al [26] than the group of researchers showed to the same sample population.

Apart from the genre, people with limb difference indicated that they would like a progressive and appropriate increase in difficulty, would like to use both hands to play the game, and would like for the game to motivate them to make enough repetitions of the trained arm to form habits. A researcher pointed out that the abstraction of the signals to rewarding or menacing game elements could be beneficial.

Challenges

Only researchers participated in this part of the survey. They were asked to formulate their opinions on the challenges that the field of games in upper limb prosthetic rehabilitation faces. In addition, they were invited to propose potential actions that could be undertaken by the community to address these challenges.

Part of the challenges mentioned by the researchers was the justification for the use or the development of serious games in prosthetic rehabilitation. The meaningful impact in terms of skill transfer to prosthetic use by myo-games must be investigated. This was stated not only for short-term effects but also for long-term benefits, when compared with other rehabilitation methods. The recognition of the difference between in-game improvement and actual benefit for prosthetic use has not yet been widely acknowledged:

> *However, most game studies focus only on in-game improvement. Now in-game improvement is a requirement for transfer to daily life performance. However, in-game improvement is not a sufficient requirement for transfer.*

Therefore, researchers have called for longitudinal and large-cohort studies in the field to show the appropriateness of the medium used and the transfer capabilities of—potentially only certain types of—games.

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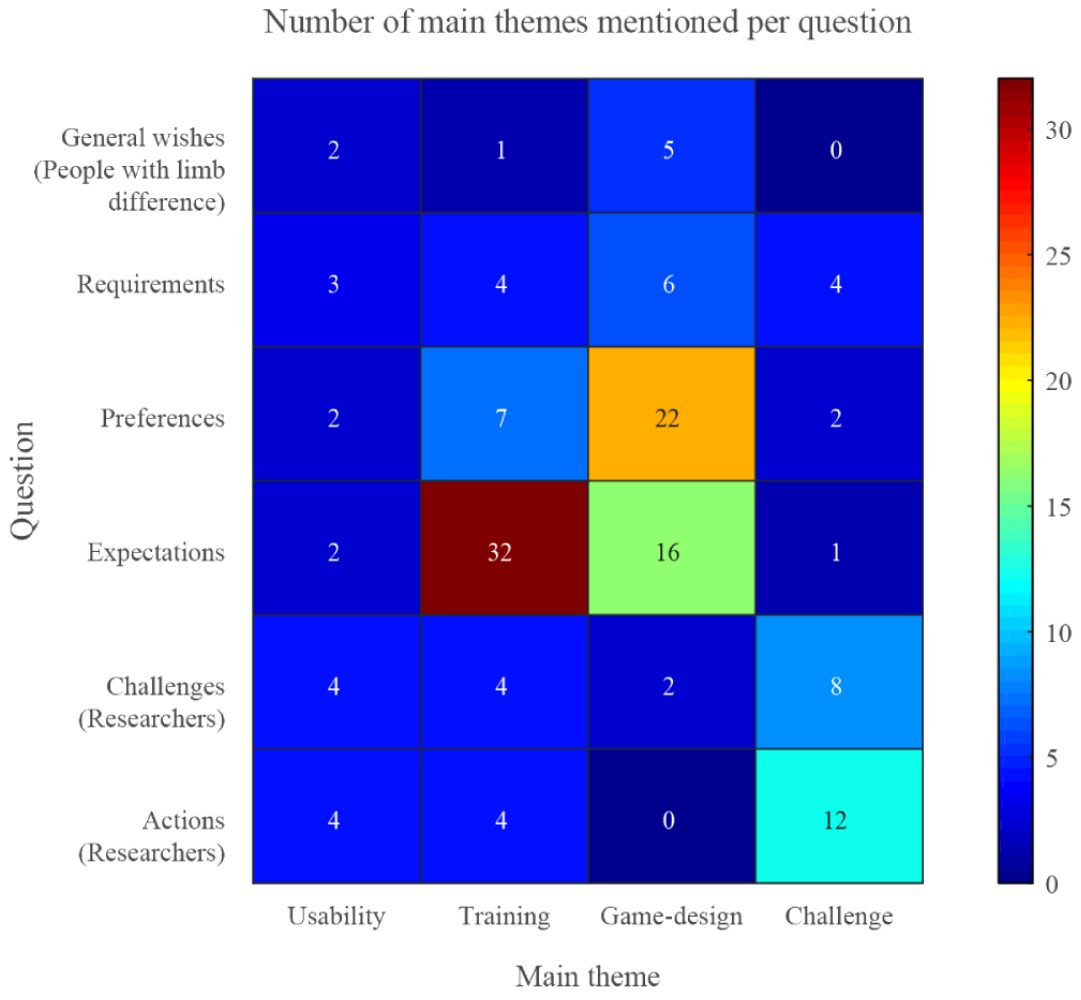
The development of these myo-games faces its own problems and challenges. They should make the benefits clearly visible for the user but at the same time make the training imperceptible by shifting the focus of the user away from the underlying reason for the training onto the task-specific in-game goals. Researchers have indicated that the formation of bad habits to win the game by potentially compromising the training efficiency should be avoided. Therefore, it was recommended to involve game developers in the process and to parallelize game development and transfer testing procedures to avoid losing sight of either aspect. One researcher proposed the development of a knowledge and information sharing platform for myo-games. He also indicated that such a platform could lead to a wider and easier access to developed games for users at home with their existing hardware.

Finally, the recognition of the value of myo-games is another key obstacle to tackle. Some people, especially certain age groups, might dismiss games as frivolous and a waste of time. Both clinicians and patients might need to be convinced that a serious game for prosthetic rehabilitation could benefit them as well as potentially benefit research. For example, a researcher suggested:

> *Educating participants about serious games and why the time they spent playing is well spent* [...]

Reviewing the number of mentions of the main themes, a clear separation of themes becomes visible. In Figure 2, it can be seen that the main expectation of the participants for the prosthetic training lies within the training benefits that it should provide. The fewer mentions of game design topics indicate that the design is of concern but that the training aspect takes priority and should be the base minimum of any game-based training. The themes of training and game design almost have the same amount of mentions overall in this survey, with 52 and 51 responses, respectively. In contrast to the clear focus on training in the expectations, the game design–related themes were more split between preferences expectations. This suggests that many game design traits are considered desirable but not a necessary component, which is reflected in some research in the field of game-based prosthetic training.

Figure 2. Number of coded responses per question and main theme over both participant groups.



Discussion

Myo-Games: Opportunities and Challenges

The aim of this study is to determine the preferences, expectations, and views of both researchers and people with limb difference on game-based prosthetic training. The outcome of this survey indicates a general willingness and tentative optimism toward the topic. However, for the wide adoption of myo-games, several scientific and engineering challenges should be addressed.

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In the following sections, we will discuss all identified challenges in the context of usability, training, and game design themes.

Usability

With respect to hardware usability, the discontinuation of the commonly used Thalmic Myo Gesture Control armband [9,13,20] means there is now a lack of low-cost, easy-to-use EMG sensors for home use. Of the commercially available dry EMG options suitable for game-based training, almost all require sensors to be accurately positioned using adhesives. As such, researchers are increasingly developing custom-built EMG acquisition solutions for game-based systems [14,18,29]. This approach does not scale well and is likely to contribute to the slow translation of laboratory research to translational research with a larger number of participants.

The accessibility of in-home myo-game software is also a key factor for overall usability. Accessibility must be balanced against client privacy and patient confidentiality, key points that therapists have identified as important in game-based upper limb rehabilitation [27]. The small target population of upper limb amputees and the niche nature of game-based rehabilitation mean cross-platform software with widespread hardware compatibility is not likely to be financially viable. The low cost of Android mobile devices and the fact that they can be locked down to a restricted set of sandboxed apps make this platform the most likely candidate for in-home use.

Training

The topic of training with regard to goals was fairly unanimous between the participants with limb difference and the researchers. In current research in this field, it appears to have mostly been assumed that an improvement in game control would translate readily to an improvement in prosthetic control as only in-game improvement or abstract control has been measured in most studies [4,6,8,12-14,20,30,31]. The question of whether this transfer can happen and with which type of game this might happen has yet to be answered, as current research challenges the idea that a general myocontrol skill exists [10,32]. However, it could prove beneficial to not only consider direct transfer but to also investigate indirect improvements like increases in training speed in learning the use of a prosthesis after training with myogames. Therapists have especially expressed that gaming in therapy should be balanced with other forms of therapy [27], and as such, it might prove beneficial to examine them in conjunction.

The only testing of the effect on actual prosthetic skill in game-based prosthetic training research was conducted on the direct effect that the developed game would have on prosthetic skill [10,15]. We could not find any study that has conducted research if the training with a game before or alongside actual training with a prosthesis could be beneficial to the learning process as opposed to an immediate effect on prosthetic skill. Prior training could be sensible as post amputation, the site of surgery may not yet be ready for the fitting of a prosthetic socket. The British Society for Rehabilitation Medicine states that the fitting may be deferred from 4 to 6 weeks after the amputation [33]. In both the amputees and people with congenital limb difference, the muscle sites could need development before a prosthesis can be considered. Training alongside real-life prosthetic training could add to the fine control without being reliant on the other arm musculature when those muscles are tired from the weight of the prosthesis.

In contrast to the popular assumption that a prosthetic training game would reduce the time investment necessary for the therapist, it should be pointed out that this is highly dependent on the type of training tool and the way it is included in the exercise regime. Almeida and Nunes [34] point out that therapists might need to be involved in the setup and fulfill a supervisory role in the exercises performed by users. Optimally, this would not be the case after the system was tested and approved apart from a first introductory session with the therapist to ensure that the user understands how to use the system properly. Therefore, ease of use is an important factor, both with respect to setting up equipment and its daily use.

Responses from the participants with limb difference group indicate that they would like a prosthetic training tool that makes rehabilitation feel less like rehabilitation. This was reflected in the call of the researchers for immersion in the game, which allowed the user to shift from their limb and muscles to the task at hand, allowing the motions to become intuitive. This can also be found as part of the Optimizing Performance Through Intrinsic Motivation and Attention for Learning theory of Wulf and Lewthwaite [35], which states that an external focus has beneficial effects on motor learning as well as the sense of accomplishment. According to that theory, the external focus as well as intrinsic motivation feed into a virtuous cycle of enhanced motor learning. However, the question of how to incorporate these aspects efficiently is yet to be answered.

Game-Design

One of the main points mentioned for the game design was the facilitation of both short- and long-term engagement. The potential users of a prosthetic training tool seem willing to take the leap to use it, which is supported by research in games for other conditions [36], but the appeal of such a novelty can quickly wane. It is the task of good game design to support the user by providing motivating gameplay for the entire training period. This again feeds into the aforementioned virtuous cycle, according to Wulf and Lewthwaite [35]. A shared experience among prosthesis users as well as between prosthesis users and able-bodied people could further enhance the motivation and potentially the training intensity [36-38].

The involvement of all stakeholders, including game developers, is a recommended path for research to take. This can be especially motivated, as game developers have more experience in catering toward a specific audience with their games and which game design elements work best to keep the users motivated to play the game. Academic teams are likely to have different views on fun themes and activities to the general population based on the differences in the user types in this study. These differences further support the need for co-design between researchers and potential end users [17,29,39]. The inclusion of the design preferences of the users as well as the input by their families can provide valuable insights for the researchers developing the games [40]. In addition, an

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understanding of the practical activities of the therapists and their involvement in game-based rehabilitation is necessary for the effective development of a training tool that benefits all parties [34]. As of yet, cocreation in the wider field of prosthetics remains difficult to integrate with current academic methods but is now becoming a focal point for translational research [Jones et al, forthcoming].

Nonetheless, this gives rise to the question of how to achieve effective targeting of the game in a highly varied target audience. Working toward increasing the engagement of a game before knowing whether transfer will happen for this game could lead to fruitless efforts. However, it is possible that engagement is a contributing factor in the transfer process and therefore worthy of further exploration.

As the current state of myo-game development is very diverse, it was expected that the opinions on the matters to focus on and the potential resolutions are just as varied.

The Survey: Strengths and Limitations

It is the first time a survey like this has been conducted in this field with these participant groups. We did not include clinicians in this survey, as a previous study covered therapists' views on the use of video games in general upper limb rehabilitation [27]. The format of the study allowed the easy spread of the survey in the field. This led to the recruitment of 12 researchers and 14 participants with limb difference. However, the sample size of the survey was smaller than would be desirable for a good cross-section of the population with limb difference as well as researchers. In an attempt to acquire many participants, this survey has been spread in various ways, but it is possible that survey fatigue has stopped people from participating. This could indicate that other means of interacting with people with limb difference might be advisable for future research. If a similar study was to be repeated in this format, we recommend collaborating on it with several research groups. This would provide access to a larger group of researchers as well as people with limb difference.

In addition, regarding the data set of the researchers, the clear majority of participants identifying as male could influence the outcome of the answers. Female researchers were included in the list, and the survey was distributed among them. However, because of the general gender disequilibrium in the field, this list already contained a higher percentage of male researchers. This could have influenced the opinions and preference distribution of the researchers, as differences in gaming preferences have been identified in both gamer and nongamer populations [41].

The Future of Myo-Games

In this study, the results indicate a higher level of similarity of the participants with limb difference group to the sample population in a study by Tondello et al [26] than of the researcher participant group compared with the same sample population. Although the low number of participants does not provide conclusive evidence in this matter, it is still worth considering the implications of this dissimilarity. The influence of personal preferences and assumptions made by the researchers could have a significant impact on the engaging and motivating aspects of the game they are developing. This could be mitigated by bringing in professional support from the game development sector or by increasing collaboration with game experts within academia, who have more practical knowledge in catering a game experience toward a diverse target audience. Moreover, this would likely benefit the efficient incorporation of features facilitating external focus and intrinsic motivation. However, as the market for serious games for upper limb prosthetic rehabilitation is fairly small and therefore the potential profit margin is small, including professional game developers in this research could prove challenging. In addition, involvement of the users, their families, and other stakeholders can provide additional benefits to the development process and should be considered.

Furthermore, the effect of myo-games has mostly been investigated in short trials of up to a week in experimental scenarios at a university or at the home of the participant. A much-improved assessment of the effect of these games in both the short term and the long term as well as whether a significant level of transfer occurs could be achieved by conducting longer-term home trials with people with limb difference. This would also provide more information about the engaging aspects of the game in the long term, that is, if the feelings of the participants change because of the waning novelty of the game and if it becomes a chore. Conversely, if the attrition over a long-term study would prove to be significantly lower than comparable experiments, this could be an indicator for a positive effect of games on exercise and training adherence. As discussed, for long-term experiments in a home environment, Android mobile devices appear to be a promising choice for hardware. In addition, the effect of myo-game training in conjunction with conventional prosthetic training could prove beneficial to assess.

The current state of isolation because of the 2020 coronavirus pandemic poses many challenges for academic research, some of which may persist in the long term. Thus, a shift in experimental procedures to the home environment of the participants could be a beneficial route to follow. Many of the technical challenges surrounding home-based experimentation, such as precision timing, low latency networking, and data security, have already been widely addressed in gaming. More widespread adoption of gaming technology to facilitate the shift of experimentation to participants' homes may provide an alternative route to bridge the gap between academic research and viable prosthesis training solutions.

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Acknowledgments

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Questions and results.
[PDF File (Adobe PDF File), 121 KB - games_v9i1e23710_app1.pdf]

Multimedia Appendix 2
Preferences and user type distributions.
[PNG File , 221 KB - games_v9i1e23710_app2.png]

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Abbreviations

ADL: activities of daily living
EMG: electromyography

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Original Paper

Video Game–Based Rehabilitation Approach for Individuals Who Have Undergone Upper Limb Amputation: Case-Control Study

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Abstract

Background: Brain plasticity is an important factor in prosthesis usage. This plasticity helps with brain adaptation to learn new movement and coordination patterns needed to control a prosthetic hand. It can be achieved through repetitive muscle training that is usually very exhausting and often results in considerable reduction in patient motivation. Previous studies have shown that a playful concept in rehabilitation can increase patient engagement and perseverance.

Objective: This study investigated whether the inclusion of video games in the upper limb amputee rehabilitation protocol could have a beneficial impact for muscle preparation, coordination, and patient motivation among individuals who have undergone transradial upper limb amputation.

Methods: Ten participants, including five amputee participants and five able-bodied participants, were enrolled in 10 1-hour sessions within a 4-week rehabilitation program. In order to investigate the effects of the rehabilitation protocol used in this study, virtual reality box and block tests and electromyography (EMG) assessments were performed. Maximum voluntary contraction was measured before, immediately after, and 2 days after interacting with four different EMG-controlled video games. Participant motivation was assessed with the Intrinsic Motivation Inventory (IMI) questionnaire and user evaluation survey.

Results: Survey analysis showed that muscle strength and coordination increased at the end of training for all the participants. The results of Pearson correlation analysis indicated that there was a significant positive association between the training period and the box and block test score (r_8=0.95, P<.001). The maximum voluntary contraction increment was high before training (6.8%) and in the follow-up session (7.1%), but was very small (2.1%) shortly after the training was conducted. The IMI assessment showed high scores for the subscales of interest, perceived competence, choice, and usefulness, but low scores for pressure and tension.

Conclusions: This study demonstrated that video games enhance motivation and adherence in an upper limb amputee rehabilitation program. The use of video games could be seen as a complementary approach for physical training in upper limb amputee rehabilitation.

(JMIR Serious Games 2021;9(1):e17017) doi:10.2196/17017

KEYWORDS

box and block test; Intrinsic Motivation Inventory; maximum voluntary contraction; motor rehabilitation; upper limb amputee; video games

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Introduction

A myoelectric prosthesis is a popular choice among upper limb amputees [1], although most users stop using it after sometime owing to control difficulties, muscle fatigue, and lack of motivation to practice before getting used to the control mechanism [2]. Myoelectric prothesis task training is required before and after prosthesis fitting [3], and it takes several months of practice under the guidance of physicians and therapists to regulate these prostheses naturally. This process is exhausting and tedious [4].

The use of interactive technology can foster intrinsic motivation and thus the effort invested in the training of neuromuscular rehabilitation [5]. Various computer-based systems, including video games, have been suggested [6-9] to support motor training. Physiological data suggest that gaming can cause neuroplastic reorganizing, leading to the long-term retention and transfer of skills; however, further clinical research is needed in this field [10]. Besides, it has been shown that virtual reality (VR) platforms, in the form of video games, provide amputees with an interactive and immersive technique for enhanced muscle coordination and overall control, which has been found to be very helpful for a patient to start training before getting an actual prosthetic hand [11].

Previous studies have shown that rehabilitation tasks based on a fun and playful concept provide better outcomes compared to traditional physiotherapy exercises [12,13]. Video games have been shown to offer some positive effects on behavior and physiology [10]. Participants who learn motor skills through games, especially in the VR setting, can have better skills in the real environment [14]. Therapy needs to have high repetition, supervision, clear rewards, and a long duration over time for maximum effectiveness [15,16]. In this case, patient motivation needs to be maintained in order to increase patient engagement and the dosage of therapy-relevant movements by incorporating these movements into an interactive environment that can enhance cognitive, motor, and affective measures [10]. Video game–based rehabilitation is popular in geriatric populations [17], people with stroke [18,19], and people with Parkinson disease [20,21]. In 2018, a similar study on upper extremity amputees and able-bodied participants showed an overall improvement in electromyography (EMG) control, fine muscle activation, and electrode separation [4].

Patient motivation was usually evaluated using Intrinsic Motivation Inventory (IMI) questionnaires and observations by physiotherapists [22-24]. This study investigated whether the inclusion of video games in the upper limb amputee rehabilitation protocol could have a beneficial impact on the course of treatment and patient motivation, with the hypothesis that the functional outcome of motor rehabilitation is directly proportional to the duration of the therapeutic session [25-27] and patient interest to take part in rehabilitation [28]. Other study outcomes measured in this work are maximum voluntary contraction (MVC) readings of the forearm muscle and the box and block test (BBT) score.

Methods

Participants

The participants of this study were five able-bodied and five transradial amputee subjects with a mean age of 26.3 years (SD 4.47), who were recruited from University Malaya Medical Centre (UMMC), Kuala Lumpur, Malaysia. Two out of the five transradial amputee participants had congenital amputation, while the other three had undergone amputation owing to traumatic injury at a mean of 3.7 years (SD 1.69) at study inclusion. One participant was a bilateral amputee; therefore, only one residual limb was considered in this study. The rest of the amputee participants had unilateral amputation (right side for all), and the amputation level ranged from long to short transradial amputation. All amputee participants had never used any prosthetic device since amputation and had no experience with an EMG system. The amputee participants were independent, could perform all activities of daily living on their own, and received no other treatment or rehabilitation throughout the study period. In this study, the amputee participants represented the test group and the able-bodied participants represented the control group.

The EMG signal generated by each participant's forearm was evaluated before the training session. Four video games (Crate Whacker, Race the Sun, Fruit Ninja, and Kaiju Carnage) and their respective control variations were assessed for suitability to be used in the rehabilitation protocol. All participants had normal vision and were guided throughout the study. Two questionnaires were administered (modified version of the IMI and the user evaluation study). The IMI questionnaire was administered at the end of the session, whereas the user evaluation study was administered at the end of each game on the 10th training session. The test was approved by the Medical Research Ethics Committee and the Ministry of Health Malaysia (approval ID: NMRR-16-2106-32880). The Medical Research Ethics Committee considered that the data collection for this study would only involve physical evaluation. Participants were required to sign a written consent form prior to the tests.

Games

The following four different games were used in this study: Crate Whacker, Race the Sun, Fruit Ninja, and Kaiju Carnage (Figure 1). The games were selected because of the suitability of the main player control to prosthesis usage and the compatibility with the Myo armband (Thalamic Lab). The main control used for Crate Whacker and Fruit Ninja is "make a fist," which can improve the overall strength of the forearm muscle. The amputee participant's residual muscle must be in good condition [29,30], and precise EMG control ability is required to control the prosthesis naturally [31]. Meanwhile, Race the Sun and Kaiju Carnage were included because of their ease of control. The game control methods are summarized in Table 1.

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Figure 1. Selected open-source games.

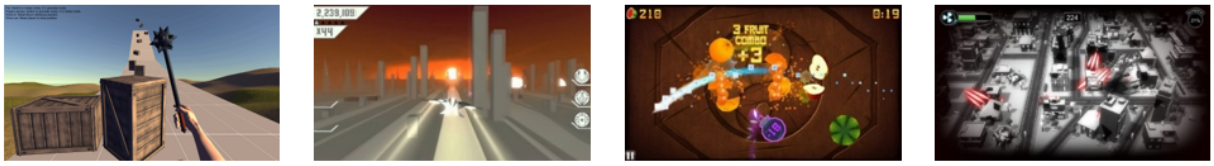


Table 1. Game control methods with the Myo armband.

Game	Player control	Action	Muscle contractions
Crate Whacker	Make a fist	Equip mace	Quick but frequent contraction
Crate Whacker	Spread the fingers	Equip grenades	Quick but frequent contraction
Crate Whacker	Wave left	Centre your arm	Quick but frequent contraction
Crate Whacker	Wave right	Reset player	Quick but frequent contraction
Crate Whacker	Pan	Smash crate	Quick but frequent contraction
Race the Sun	Make a fist	Center position	No contraction
Race the Sun	Spread the fingers	Open menu	No contraction
Race the Sun	Wave left	Mouse click	No contraction
Race the Sun	Wave right	Enable/disable mouse control	No contraction
Race the Sun	Pan	Fly side to side	No contraction
Race the Sun	Rotate	Jump up or down	No contraction
Fruit Ninja	Make a fist	Cut the fruits (hold)	Prolonged contraction
Fruit Ninja	Double tap	Move mouse	Prolonged contraction
Fruit Ninja	Pan	Unlock (hold) or lock	Prolonged contraction
Kaiju Carnage	Make a fist	Charge/release kaiju shockwave	Combination of gestures
Kaiju Carnage	Wave left	Recalibrate Myo armband	Combination of gestures
Kaiju Carnage	Pan	Quickly swipe with the hand for kaiju claw	Combination of gestures
Kaiju Carnage	Rotate Hold arm up	Charge/unleash kaiju beam	Combination of gestures

The keyboard mapper utility available in Myo Connect was used to assign keyboard and mouse commands to any of five gestures to control the game. The gestures used to control the games included fist, wave in, wave out, finger spread, and double tap. Pan motion from highly sensitive motion sensors embedded in the Myo armband is important as it allows the player to move in the game setting. The custom configuration for each game is exported as connector scripts. In Crate Whacker, the player repeatedly smashes the crate with a mace and destroys them with grenades. The player controls the mace position with the acceleration and gyroscopic data of the armband. In Race the Sun, the player controls a solar-powered spacecraft, dodging various objects on the way, such as laser beams, other ships, and other stationary obstacles, while collecting pick-ups that can be used in the game, with the sun slowly setting on the horizon. The game ends either when the player hits an object and the ship gets destroyed or when the sun sets. Meanwhile in Fruit Ninja, the player needs to slice the fruit into half to collect point. The Kaiju Carnage game enables the player to claw, smash, and shoot nuclear lasers on buildings.

Experimental Protocol

The set up for this study includes a monitor that displays the game that the participant plays with the Myo armband connected via Bluetooth. The system utilized commercially available equipment of the Myo gesture control armband. It consists of eight plastic pods held together by a rubber lining that measures 7.5 inches (19.05 cm) in circumference and can be extended to 13 inches (33.02 cm). There are three medical steel EMG sensors on the bottom of each pod, which are responsible for reading the muscles' electrical activity and arm movement. With the use of a machine learning process, the armband can recognize the gesture perform based on the electrical activity of the arm in real time. Amputee participants wear the Myo armband on the affected limb. Able-bodied participants wear the armband on the dominant hand. Ten 1-hour sessions were carried out within a 4-week period. Participants were initially

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instructed to perform the VR BBT designed by the authors, and provisional MVC levels were recorded before the four Myo-controlled computer games were introduced to each participant in a randomized order. Randomization of the games was performed by the study facilitator. At the end of the training session, the MVC value was recorded again, and a modified IMI questionnaire and a simple user evaluation survey regarding the gaming experience, similar to the approach in the study by Prahm et al [32], were administered to the participants. Follow-up MVC values were taken 2 days after the last intervention session.

Assessment

In order to investigate the effect of the video game rehabilitation protocol used in this study, VR BBTs and basic EMG assessments evaluating approximate coordination and muscle strength were performed. The participants were asked to perform the BBT in a virtual environment (Figure 2). The test was made up of the following two phases: an initial 15-second phase, where the user gets a trial run, followed by a scored 60-second phase. Participants were told to move as many blocks as possible in a span of 60 seconds (one by one) from one compartment to another. The participant's hand must cross over the partition in order for a point to be given, and blocks that drop or bounce out of the second compartment onto the floor are still rewarded with a point. The instructions are scripted, and they were read to each user according to the manual for the test. The experiments were performed according to the World Medical Association Declaration of Helsinki [33]. The player needs to move the virtual hand near the cube, contract the forearm muscle to pick the cube up, and then stop contracting the muscle to release the cube into another compartment. The score generated on the top left of the screen refers to the amount of successfully transferred blocks, and the red line on the top right corner of the screen refers to the linear timer (Figure 2).

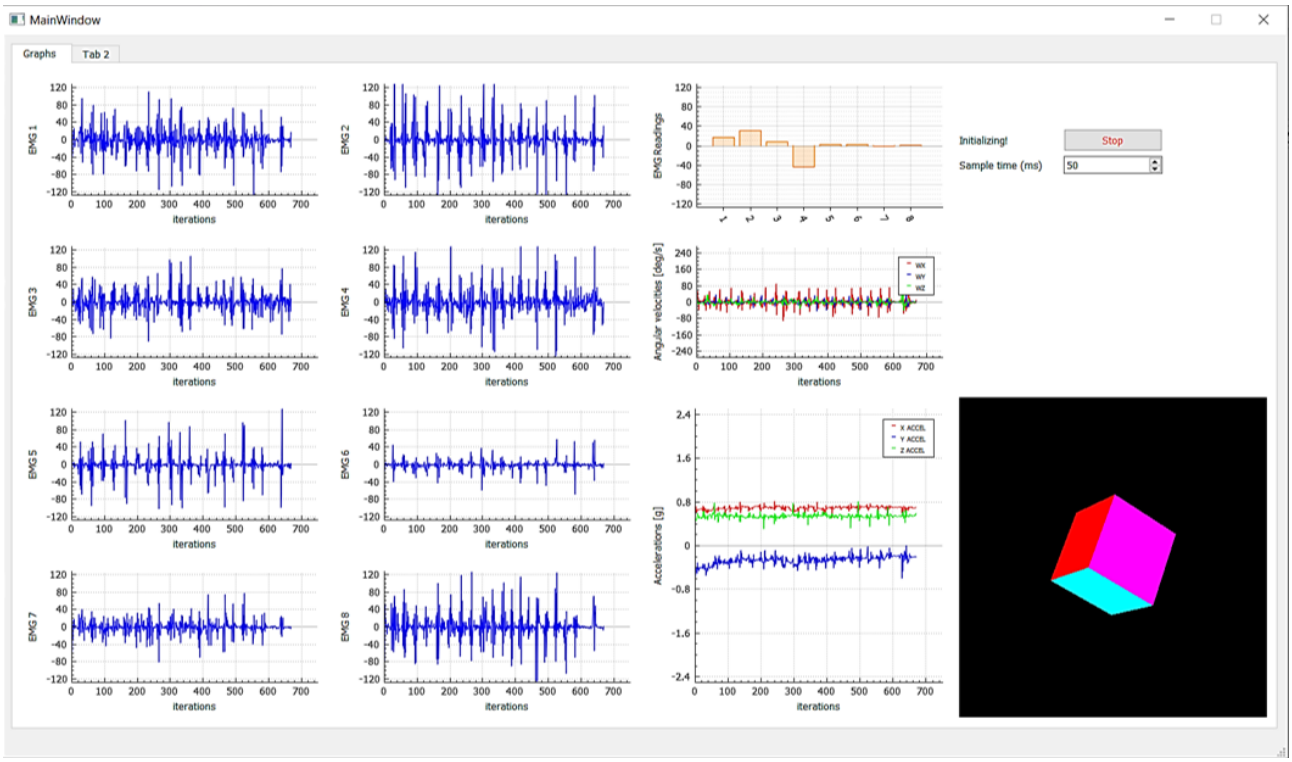
Figure 2. A transradial amputee participant performing the virtual box and block test.



The MVC was recorded for each participant before, immediately after, and two days after playing the game. Participants were instructed to maximally contract their forearm muscle and to hold this contraction for 10 seconds, and the highest value was recorded as the MVC value. The assessment was carried out with the Myo visualization tool (Figure 3) on a laptop with a discrete graphics processing unit (NVDIA GeForce GTX 1060) for signal acquisition, filtering, calibration, training, and prediction. The Myo visualization tool is an open-source Myo armband data reader created using Myo SDK, Qt Creator, and QCustomPlot that streams and displays the EMG signal and accelerometer, gyroscope, and orientation data of the Myo armband.

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Figure 3. The Myo visualization tool interface that streams the electromyography (EMG) signal detected by the armband. The first two columns represent the EMG sensors detected by pods 1-8. In the third column, the first graph on the top is the EMG representation as a whole, while the other two are angular velocities and accelerations.



Questionnaires

Two questionnaires were provided for each participant to be completed at the end of the training session, which included a modified IMI questionnaire [3] and a user evaluation survey [32]. The participants' experiences with each game were evaluated using the IMI questionnaire, which has previously been used with a virtual environment for motor rehabilitation [22-24]. A modified version of the IMI questionnaire made up of five selected subscales was utilized to evaluate participants' experiences with the protocol. The subscales included were interest/enjoyment, perceived competence, perceived choice, pressure/tension, and value/usefulness. The questionnaire included statements such as "I found this activity very interesting," and they were rated on a 7-point Likert rating scale from 1 (not true) to 7 (true).

A brief questionnaire about the gaming experience was presented after the completion of each game. This short survey included questions about the gameplay, fun factor, motivation, and input and control methods, and it included the following questions: (1) Did you like this game in general? (2) Did you have fun playing the game? (3) How would you rate the input mechanism? (4) How would you rate the game control? (5) Did this game motivate you? Question could be answered on a 5-point Likert scale ranging from 1 ("do not agree") to 5 ("agree"). The participants were asked to focus on the differences between each game and to avoid giving the same answer to one statement for all the games if possible.

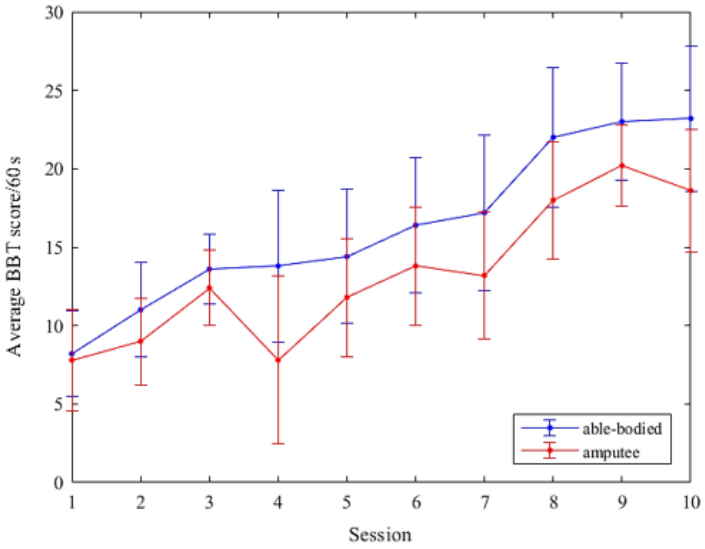
Results

In this study, we showed that incorporating video games in an upper limb amputee rehabilitation protocol would provide benefits to the rehabilitation output. The platform consists of four video games controlled by an off-the-shelf Myo gesture control armband. The games were played by five able-bodied and five transradial amputee participants. The use of the four video games was widely explored in this context. No technical difficulties were encountered with the game settings.

The average BBT score in every training session gradually increased, with the mean score reported in the 10th training session of this study being 23.2 (SD 4.62) in the control group and 18.6 (SD 3.93) in the test group (Figure 4). The results of the Pearson correlation assessment indicated that there was a significant positive association between the training period and the BBT score (r_8=0.95, P<.001). The highest score achieved was 29 blocks transferred over 60 seconds by one able-bodied participant during the final session.

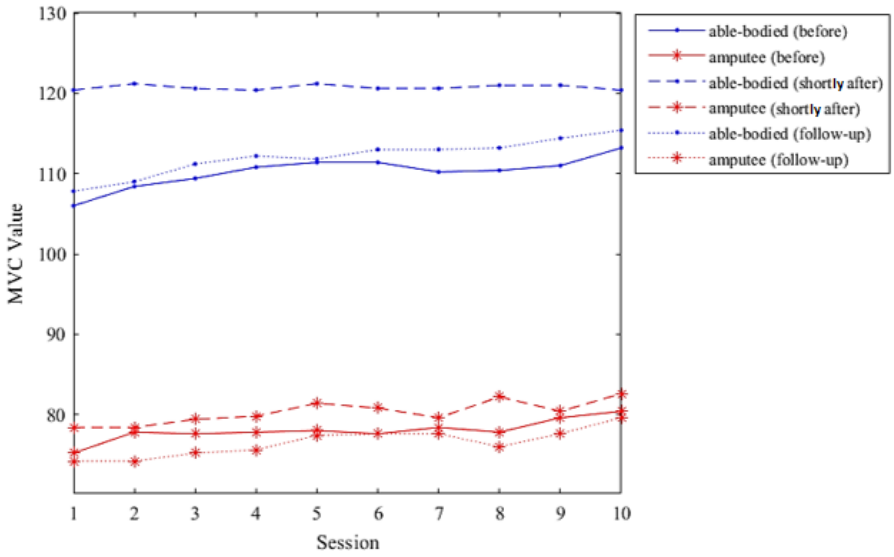
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Figure 4. Mean score in the box and block test per 60 seconds over 10 training sessions.



From sessions 1 to 10, the MVC value for able-bodied participants increased during follow-up and shortly after the training was conducted, but not immediately after the training session. This may be caused by muscle fatigue. Meanwhile, for amputee participants, the MVC value increased before and shortly after the training was conducted, and during the follow-up session (Figure 5). This proves that the muscle strength of all participants increased with the training duration. Shortly after the training session, six out of 10 participants showed an improvement in the MVC value from the initial to the final session, two participants showed no improvement, and two participants showed a reduction in the MVC value at the end of the training session. In the follow-up session, nine out of 10 participants showed an improvement in the MVC value compared to the initial training session. The MVC increment was greater before training and in the follow-up session but was very small (approximately 2.1%) shortly after the training was conducted.

Figure 5. Mean maximum voluntary contraction (MVC) values before and shortly after training and during the follow-up session.



The results obtained from the IMI questionnaire are shown in Table 2. Participants had high interest in playing the games, perceived playing the games as their own choice, and felt competent and at ease while playing the games. Participants also agreed that this activity provided benefits that included strengthening their muscles, motivating them, and keeping them active, resulting in higher motivation to perform the activity for a longer period of time. Pressure or tension was the only subscale with a low reported average score. The difference in the scores for both groups was insignificant for all subscales, except for the perceived choice subscale (d=0.58).

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Table 2. Intrinsic Motivation Inventory questionnaire results based on five subscales.

Subscale	Likert scale score, mean (SD)[a]	
	Able-bodied participants	Amputee participants
Interest/enjoyment	6.8 (0.40)	6.6 (0.49)
Perceived competence	6.2 (0.75)	6.2 (0.40)
Perceived choice	5.8 (0.75)	4.4 (0.49)
Pressure/tension	1.8 (0.75)	2.0 (0.63)
Value/usefulness	6.4 (0.80)	6.2 (0.40)

[a]Score range: 1 (low) to 7 (high).

According to the results of the user evaluation survey (Table 3), the favorite game (derived from the score of question 1 and question 2) was Race the Sun, followed by Fruit Ninja, Crate Whacker, and Kaiju Carnage. There was no difference in the distribution of the games for both general and fun categories, but a significant difference was observed in Crate Whacker, where amputee participants appeared to less enjoy Crate Whacker compared with able-bodied participants (P<.001).

Table 3. Results of the user evaluation survey.

Category	Score							
	Able-bodied participants				Amputee participants			
	Crate Whacker	Race the Sun	Fruit Ninja	Kaiju Carnage	Crate Whacker	Race the Sun	Fruit Ninja	Kaiju Carnage
General	3.6	4.2	4.2	1.6	3.2	4.4	4.2	1.4
Fun	3.6	4.2	4.2	1.6	3.0	4.2	3.8	1.6
Input	3.6	3.8	4.0	1.6	3.4	4.2	4.4	1.4
Game control	4.0	3.8	4.2	1.8	3.0	4.2	4.6	1.2
Motivation	3.8	3.8	4.4	1.6	3.6	3.8	4.0	1.6

Discussion

Principal Findings

An important finding from this study lies in the usage of the platform in 10 1-hour sessions within a 4-week period. The BBT is a standard test to assess hand functionality [34,35]. In this study, the test was used in a virtual setup in order to check the participants' ability to control and operate a myoelectric hand, as the mechanism utilized to pick and place an object in the virtual setting is similar to that for a myoelectric prosthesis. Compared to the mean conventional BBT score for a healthy person as reported by Mathiowetz [34], which is in the range of 78.9 (SD 15.3) to 75.1 (SD 11.1) per 60 seconds, the score for the virtual setup was very low (approximately 74% lower score). However, the mean score increased from session 1 to 10.

The MVC test is a standardized method for measurement of muscle strength [36]. The results obtained demonstrate improvements in muscle strength from pregaming to follow-up assessments. A high increment was observed among amputee participants after playing the game, which is consistent with the finding in the study by Prahm et al [32]. This result may be associated with the electrode resistance that may be affected by a change in body temperature or sweat, which, at the same time, proves that the use of video games in upper limb amputee rehabilitation is not fatiguing for the participants. It can be safely said that certain improvements in EMG control could be detected by the MVC test. Besides, from the results, MVC values recorded for able-bodied participants were greater than those for transradial amputee participants, with the lowest MVC value recorded for an amputee participant with congenital amputation, which may have been associated with muscle atrophy. Atrophy of the remaining muscle occurs when the muscle is not used for long periods of time, and the EMG signal becomes very weak after amputation [37]. Male participants recorded greater MVC values compared to female participants.

Based on the IMI questionnaire and user evaluation survey conducted, the motivational aspects of training gamification were traceable. Participants agreed that the activity can induce desirable physiological changes that are consistent with the findings in the study by Lohse et al [10]. Pressure (psychologically) could be felt by amputee participants while playing the Race the Sun game because of its difficulty level. Nevertheless, the participants were still motivated to play the game according to the survey conducted. It has been reported that enjoyment, control mechanisms, music, direct feedback on scores, and ability to receive upgrades influence a player's motivation [32], and choice, rewards, and goals lead to increased engagement [10].

Aside from game suitability and main player control, the four games were included in this study because each of the games involved a different engaging element. Crate Whacker is continuous without a specific time limit, scoring system, and

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level upgrade. Race the Sun and Fruit Ninja have both a scoring system and specific time to complete the game, but the player can receive upgrades only in Race the Sun. Meanwhile, in Kaiju Carnage, a specific time limit is available, but the player receives no score or upgrade. All games, except for Kaiju Carnage, have no background music. The majority of the participants reported that they enjoyed and wanted to continue playing Race the Sun and Fruit Ninja after the training period, which indicated increased participant motivation as reported in previous studies [25-27]. Both of these games provide direct feedback for the player interaction, and the player can see the timer and score obtained clearly while playing, which is supported by the findings of Liepert et al [15]. According to question 3 and question 4, participants preferred the control in Fruit Ninja, as they felt that they were slicing the fruit in the game with their own hands. A significant difference in the score distribution was observed in Crate Whacker and Kaiju Carnage under game control input ($P<.001$), indicating that amputee participants had control difficulty in these games. In terms of motivation (question 5), all of the participants only felt less motivated while playing Kaiju Carnage owing to lagging in EMG control and long loading time. Participants also reported that this game showed no score while playing, had a low level of difficulty, and was not interesting. In addition, all amputee participants appeared to be struggling to imitate the clawing gesture, but this was not the case with able-bodied participants. This part of the study showed that engaging elements contribute to increasing a player's motivation during rehabilitation.

Conclusions

This study demonstrated that a video game–based rehabilitation protocol can be used as a complementary method for upper limb amputee rehabilitation. Participants showed greatly improved muscle strength, coordination, and control. A good muscle condition and induced neuroplasticity enabled better control in the BBT, which is related to readiness to use a myoelectric prosthesis. Participants agreed that this activity is beneficial to them both behaviorally and psychologically. According to the questionnaire responses, it could be shown that the use of video games maintains patient interest during training, therefore improving patient motivation and exercise intensity and enhancing adherence throughout the rehabilitation period. The engaging elements in the game could be identified with the questionnaire. Video games with high intensity and difficulty create pressure for the player, but not all Myo-controlled video games are suitable for transradial amputee rehabilitation.

Acknowledgments

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Conflicts of Interest

None declared.

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Abbreviations

BBT: box and block test
EMG: electromyography
IMI: Intrinsic Motivation Inventory
MVC: maximum voluntary contraction
VR: virtual reality

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Original Paper

A Depth Camera–Based, Task-Specific Virtual Reality Rehabilitation Game for Patients With Stroke: Pilot Usability Study

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Abstract

Background: The use of virtual reality is popular in clinical rehabilitation, but the effects of using commercial virtual reality games in patients with stroke have been mixed.

Objective: We developed a depth camera–based, task-specific virtual reality game, Stomp Joy, for poststroke rehabilitation of the lower extremities. This study aims to assess its feasibility and clinical efficacy.

Methods: We carried out a feasibility test for Stomp Joy within representative user groups. Then, a clinical efficacy experiment was performed with a randomized controlled trial, in which 22 patients with stroke received 10 sessions (2 weeks) of conventional physical therapy only (control group) or conventional physical therapy plus 30 minutes of the Stomp Joy intervention (experimental group) in the clinic. The Fugl-Meyer Assessment for Lower Extremity (FMA-LE), Modified Barthel Index (MBI), Berg Balance Scale (BBS) score, single-leg stance (SLS) time, dropout rate, and adverse effects were recorded.

Results: This feasibility test showed that Stomp Joy improved interest, pressure, perceived competence, value, and effort using the Intrinsic Motivation Inventory. The clinical efficacy trial showed a significant time-group interaction effect for the FMA-LE (P=.006), MBI (P=.001), BBS (P=.004), and SLS time (P=.001). A significant time effect was found for the FMA-LE (P=.001), MBI (P<.001), BBS (P<.001), and SLS time (P=.03). These indicated an improvement in lower extremity motor ability, basic activities of daily living, balance ability, and single-leg stance time in both groups after 2 weeks of the intervention. However, no significant group effects were found for the FMA-LE (P=.06), MBI (P=.76), and BBS (P=.38), while a significant group interaction was detected for SLS time (P<.001). These results indicated that the experimental group significantly improved more in SLS time than did the control group. During the study, 2 dropouts, including 1 participant who fell, were reported.

Conclusions: Stomp Joy is an effective depth camera–based virtual reality game for replacing part of conventional physiotherapy, achieving equally effective improvement in lower extremity function among stroke survivors. High-powered randomized controlled studies are now needed before recommending the routine use of Stomp Joy in order to confirm these findings by recruiting a large sample size.

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KEYWORDS

virtual reality; rehabilitation; stroke; lower extremity; rehabilitation game

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Introduction

There are 800,000 new or recurring incidences of stroke annually in the United States; the number is rising as the population ages. More than half of stroke survivors live with at least one type of motor impairment [1]. In China, there are approximately 2 million incidences of a stroke every year. Among these stroke survivors, 70% to 80% cannot live independently as a result of multiple impairments, such as motor impairments with loss of strength, stereotypic movements, changes in muscle tone, and limitations in activities [2]. For many patients with stroke, balance and weight shift management constitute a risk for secondary injury. Lower extremity (LE) functional deficits in patients after stroke have aroused a great amount of attention because they play a vital role in stroke survivors' quality of life [1,2]. Although stroke (new and recurring) remains prevalent, the number of available therapists is far from meeting the need, since the development of physical therapy has still not matured [3,4]. Rehabilitation technologies have the potential to increase the intensity and dose of rehabilitation, improve access to rehabilitation, reduce the workload of therapists, measure and provide feedback about performance and recovery, and engage and motivate patients [5-7]. Evidence-based medicine shows that high-intensity, repetitive, task-specific training tends to benefit patients greatly [8]. However, it is difficult to implement high-intensity, repetitive, task-specific training in a real clinical setting for a variety of reasons, including limited necessary resources and difficulty maintaining patients' interest. Therefore, virtual reality–based gaming systems have become popular in medical rehabilitation and can be used as a novel alternative therapy method for motor recovery after stroke.

Kinect (Microsoft) is the leader in commercially available low-cost virtual reality (VR) hardware. This is because most of the Kinect's games are aimed at the average person, and there are many more games designed by research teams for people with stroke, especially for upper limb motor function. However, there are few games focused on lower limb motor function [9]. VR, also known as immersive multimedia or computer-simulated reality, is a computer technology that replicates an environment, real or imagined, and simulates the user's physical presence and environment to allow for user interaction and immersion. Virtual realities artificially create sensory experience, which can include sight, touch, hearing, and smell [10]. VR systems consist of a development platform, display system, interaction system, and integrated control system [11]. To realize the complete information interaction between computers and humans, normally we need some external device or devices to record the user's movements. Among the kinds of external devices are force or tactile feedback systems, position trackers, data gloves or 6-degrees-of-freedom space mice, joysticks, and the Kinect sensor [11-13]. Kinect allows users to play without holding a game controller, which means they will not be bothered by wearing sensors that can be intrusive. This also saves time. Zhu et al [14] showed that the Kinect motion capture system was reliable and that the correlation coefficient of the dynamic track was quite good. A large number of clinical studies have shown that the accuracy of the Kinect somatosensory technology sensor for posture control and evaluation can fully meet the needs of body motion evaluation [15-17]. Eltoukhy et al [18] indicated that Kinect-based assessment might provide clinicians a simple tool to simultaneously assess reach distances while developing a clearer understanding of lower extremity movement patterns. Park et al [19] showed that the use of additional VR training with the Xbox Kinect gaming system was an effective therapeutic approach for improving motor function during stroke rehabilitation.

However, these systems were not specifically developed for patients after stroke, and those training sessions might produce multiple effects [20]. Those studies did not assess the flow experience of users, and few of them conducted a clinical randomized controlled trial. To address these issues, we developed a depth camera–based game, Stomp Joy, specifically for the lower limbs of patients with stroke. We also applied two principles of game design that are highly relevant to rehabilitation. The aim of this study was twofold: (1) develop a depth camera–based, task-oriented rehabilitation game for patients with stroke and (2) assess its usability and conduct a pilot study for stroke survivors' LE rehabilitation.

Methods

Depth Camera–Based, Task-Oriented Rehabilitation Game

We developed a depth camera–based, task-specific rehabilitation game called Stomp Joy, which provides an enjoyable game for people with stroke in a rich interactive rehabilitation setting. The system is shown in Figure 1. The patient stands in front of a monitor facing an OpenNI–compliant depth sensor, the PrimeSense 3D Awareness Sensor (Apple Inc) with infrared projectors combined with standard RGB and infrared complementary metal-oxide semiconductor (CMOS) image sensors. The sensor has an effective angle of 70, a distance range of 0.8 to 3.5 m from where it is located, and a response time of 10 ms. A computer operated by Windows 7 with a 3.1-GHz quad-core central processing unit and 4 GB of SDRAM renders the images onto a 46-inch monitor with a resolution of 1920 × 1080 pixels. Its normal operating conditions are an environment temperature of 10 C to 35 C and a relative humidity of 35% to 75%. Stomp Joy can be operated by both the physical therapist and the patient via a local area network, providing control of the patients' training modules and the level of difficulty.

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Figure 1. A participant experiencing Stomp Joy.



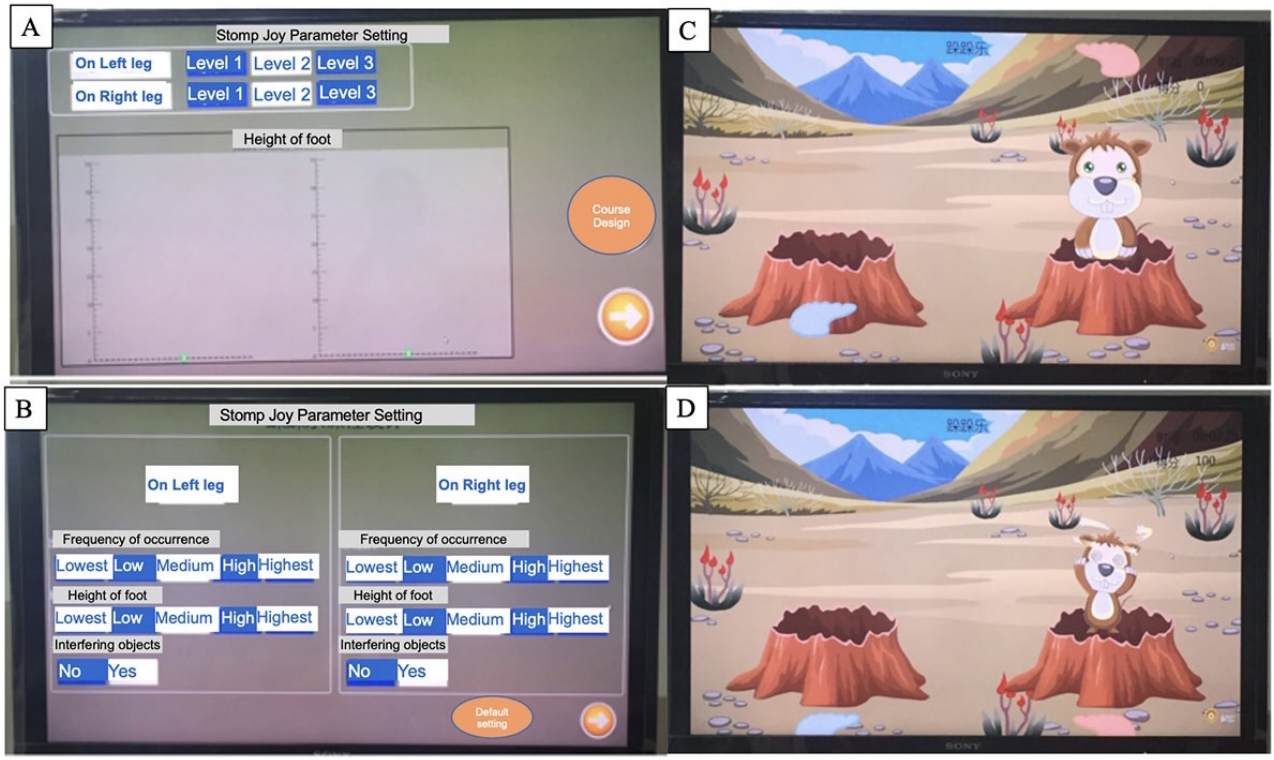
Prior to each intervention session, a physiatrist responsible for the patient's clinical situation outlined the customized training and gaming tasks, which were then further modified by the physical therapists during the actual training sessions.

The main user interface for Stomp Joy comprises 3 elements: (1) an introduction module that contains instructions about how the participant should play this game; (2) a rehabilitation curricular design module that contains different choices of difficulties for therapists and patients to choose; and (3) a rehabilitation game, Stomp Joy, that provides a repeated exercise motion using gaming concepts.

Stomp Joy was created to meet patients' need to improve their ability to transfer weight and recover to normal gait. In this game, the patient needs to lift their legs alternately to achieve the goal of transferring their center of gravity while supporting themselves on a single leg, with hip, knee, and ankle in coordination during the initial, middle, and end stages of the walk cycle. Stomp Joy was designed to increase lower limb control, endurance, speed, accuracy, range of motion, and trunk movements from synergistic motion patterns. The patient is asked to stand in front of the monitor and lift a foot to step on gophers by performing hip flexion and extension, knee flexion and extension, and single-leg support. Here, the frequency of gophers appearing on the display, the height of the gophers, and whether interference objects appear are controlled by therapists and patients, which means both therapists and patients (instructed by therapists) could select different difficulty levels of the game according to the patient's performance. Game control and operation is very intuitive. The patient performs the lower limb exercise by mimicking stepping on gophers. The position of the footprint is reflected by the flexion of the hip joint; the bigger the flexion angle, the higher the footprint. The falling of the footprint was controlled by changing the flexion angle of the knee joint. When the color of the footprint changes to pink from white, which means that the hip and knee joint flexion angles both meet the requirement, it triggers a stampede action, and the patient can then complete a successful stomp. The game has gentle and pleasant background music. When the successful completion of a stomp happens, a gong sound plays. When the patient cannot complete the stomping successfully, the gopher on the screen plays a mocking sound for feedback (Figure 2).

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Figure 2. (A) The 3 difficulty levels for the left and right feet and the unique lifting foot height recognition interface. (B) The system-specific adjustment of the curriculum difficulty's design according to patient conditions and default settings. (C) The patient raises their right foot, and when the hip and knee flexion reach the requirements of this level, the footprints above the gopher will turn from white to red. (D) When patients step down with the right foot, it shows an image of the gopher fainting.



Participatory Design and Usability Test

Patients with stroke, physical therapists, and physiatrists were involved in the design of Stomp Joy. During the development process, we categorized and applied the feedback and suggestions from 3 representative user groups. Then, we carried out a usability test to assess Stomp Joy from the view of each stakeholder group. The patients with stroke performed 30-minute Stomp Joy sessions at regular intervals 5 times a week for 2 weeks under the supervision of physical therapists and physiatrists.

Since the most important benefit of Stomp Joy is the engagement of patients, we assessed the ability of Stomp Joy to provide strong motivation and enjoyment, followed by optimal flow experience [21]. The Intrinsic Motivation Inventory (IMI) is a multidimensional measurement scale that can assess participants' subjective experience, then apply a new activity in a laboratory environment [22-26]. To assess the experience provided by Stomp Joy, we examined 5 constructs shown by usability professionals to characterize the optimal flow state for new activities: interest and enjoyment, pressure and tension, perceived competence, value and usefulness, and effort and importance [23,27,28]. We excluded perceived choice and relatedness. To test if Stomp Joy afforded the patients with stroke a desirable level of rehabilitation, we conducted a usability test in 11 patients with stroke and collected their responses to whether they were highly engaged and considered the user experience pleasant so that they were further motivated to take an active part in the Stomp Joy intervention. We conducted a semistructured, one-on-one interview with the patients with stroke, physical therapists, and physiatrists. Based on the existing literature, 3 frameworks from implementation science (normalization process theory, conceptual framework for implementation fidelity, and the Consolidated Framework for Implementation Research) were used to address the study objectives [29]. The interviews were conducted by the first and second author. Interviews took place face to face at the worksite at a time suitable to the participants.

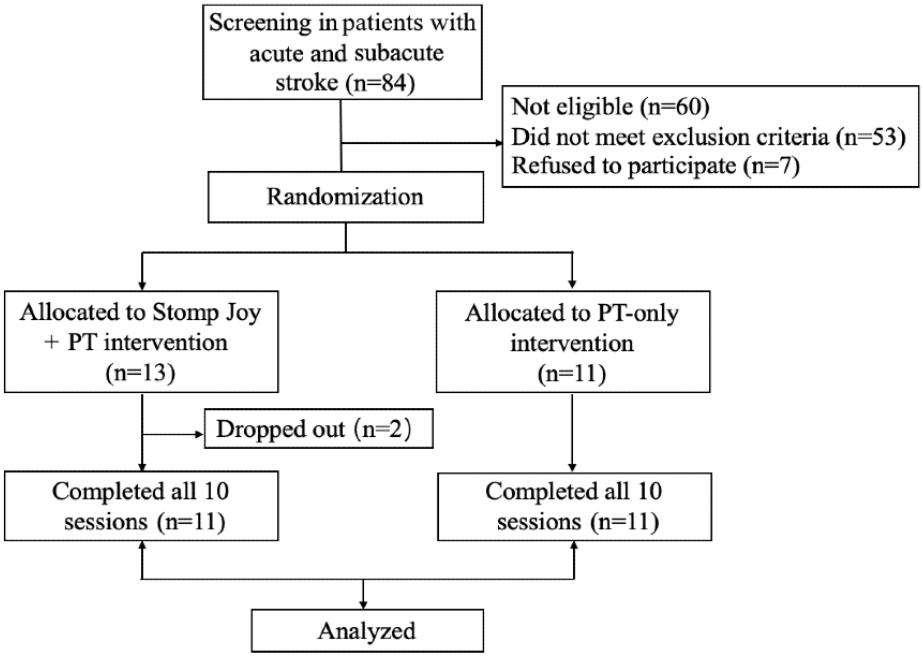
Clinical Experiments

Patients with hemiparetic lower limb dysfunction secondary to first-ever stroke were recruited from the First Affiliated Hospital of Jinan University from January 2015 to September 2016. All patients exhibited mild to severe deficits of the paretic lower extremities (≥3 on the Brunnstrom stages of motor recovery for the proximal part of the lower extremity [30], the hip and knee flexion reach [31]). The exclusion criteria were preexisting lower limb impairment, any painful condition affecting the lower limbs, difficulty standing for at least 30 minutes, severe cognitive impairment (Mini-Mental State Examination score less than 22 points [32]), and severe aphasia. The exclusion criteria were kept to a minimum in order to evaluate the feasibility of the use of Stomp Joy among a variety of patients. All patients provided written informed consent to participate and written informed consent for the publication of their clinical image. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Jinan University. The individual in Figure 1 also gave permission to publish their image.

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A prospective single-blind pilot study was conducted in patients with acute and subacute stroke. We randomized the patients to receive 10 sessions over 2 weeks of either conventional physical therapy (PT) plus 30 minutes of Stomp Joy training (Stomp Joy + PT group) or conventional physical therapy alone (PT-only group). The PT was delivered for 30 minutes by a trained physical therapist who was blinded to the protocol in order to provide participants the same PT content in the conventional clinical setting. The trained assessor was also blinded to patients' allocation and randomization to minimize assessor bias. The primary outcome was the Fugl-Meyer Assessment for Lower Extremity (FMA-LE) [33], and the secondary outcomes were the Modified Bathel Index (MBI) [34], Berg Balance Scale (BBS) [35], and single-leg stance (SLS) time [36]. The SLS time was collected 3 times by recording the endurance time of standing on the paretic limb. The patient could not touch any object while supporting themselves on one leg, and the average time was calculated after 3 repetitions were measured. Between each repetition, the patient got 1 minute to rest. These assessments were made at baseline and during the last session (tenth session) by evaluators who were blinded to the type of intervention. Adverse effects related to the Stomp Joy intervention and the number of patients who dropped out during the study period were also recorded (Figure 3).

Figure 3. Flowchart of the study. PT: physical therapy.



Statistical Analysis

One-sample 2-tailed *t* tests against the neutral value in the 7-point Likert rating were used to assess the responses to the 5 domains of the IMI [22]. A mean rating above 4 indicated that on average the patients agreed rather than disagreed with the statement.

Data were analyzed using IBM SPSS version 24.0 (IBM Corp). The baseline data (height, weight, age, time since stroke, type of stroke [hemorrhage or infarction], region of stroke [left or right]) between the two groups were compared using 2 independent-sample *t* tests and Fisher exact tests (gender). The main effects of time, group, and time-group interaction were analyzed using repeated-measures one-way analysis of variance (ANOVA) with a Greenhouse-Geisser correction to compare the changes in the FMA-LE, BBS, and MBI scores and the SLS time between the experimental group and control group. The level of statistical significance was $P<.05$ for all comparisons.

Results

Participatory Design and Usability Test

We interviewed 3 representative user groups (ie, patients with stroke, physical therapists, and physiatrists) to collect the key elements of an interactive VR rehabilitation system (Table 1). We prioritized and incorporated those key elements into Stomp Joy.

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Table 1. Key elements of a depth camera–based, task-specific virtual reality rehabilitation game [37].

Component	Key elements
Device	OpenNI–compliant depth sensor, stable system
Design	Goal-oriented task-specific contents; interactive and interesting elements; and easy-to-understand tutorials to show explanation, evaluation, and training and increase motivation for rehabilitation
Difficulty level	Easy to know how to interact, adjustable to match individualized performance
Scoring	Scoring system to record and compare performance status
Sound	Sound showing feedback of the performance, exaggerated effects sounds to improve motivation

The advantages reported by each user group after initial testing of Stomp Joy included that it provided a new immersive experience for patients with stroke and improved their motivation and attention, released part of the burden on physical therapists and helped them manage the intervention programs, and helped physiatrists conduct an effective individualized intervention.

Table 2 shows the scores across the 5 main components of the flow experience (ie, interest and enjoyment, pressure and tension, perceived competence, value and usefulness, and effort and importance), which exhibited a consistent pattern. For all 5 subscales, the patients with stroke gave higher ratings. They found that the Stomp Joy training was enjoyable and useful. Additionally, they felt they exerted effort when playing the game.

Table 2. IMI of the Stomp Joy intervention among patients with stroke.[a]

IMI[b] subscale	Rating, mean (SD)	t test (*df*)	*P* value
Interest and enjoyment	5.91 (1.09)	5.8 (10)	<.001
Pressure and tension	1.77 (0.90)	–8.17 (10)	<.001
Perceive competence	5.50 (1.00)	4.98 (10)	.001
Value and usefulness	5.77 (1.03)	5.69 (10)	<.001
Effort and importance	5.32 (1.27)	3.44 (10)	.006

[a]All of the statements used in this study were deliberately rephrased in positive terms that the patients could easily understand.

[b]IMI: Intrinsic Motivation Inventory [22].

To see if the physical therapists could easily apply Stomp Joy, we collected suggestions from 5 physical therapists who took part in Stomp Joy through semistructured interviews. Of the 5 physical therapists, 4 strongly agreed with the following statements: “I can easily allocate the rehabilitation program according to the evaluation via Stomp Joy to patients with stroke,” “I can easily manage the prescription using Stomp Joy,” and “I can tell from patients’ faces that they were glad to see that their feet on the screen could do more than in reality.” One of the physical therapists reported, “The game was a little bit repetitive, so after 10 sessions, patients could not maintain their interest.” This physical therapist also reported that the system did not have a recording system that they could track each patient’s performance.

To evaluate whether Stomp Joy played a meaningful rehabilitation role for patients with stroke, we conducted semistructured interviews with 5 physiatrists who took part in the Stomp Joy intervention. Of the 5 physiatrists, 3 reported that Stomp Joy seemed to be an effective and easy way to administer PT and that it seemed to be more efficient when conducted in the clinic. Still, 1 physiatrist reported that Stomp Joy needs to be supervised by a therapist and thus would not help save therapy resources. Another physiatrist reported that Stomp Joy needs to expand its game content so that it could be suitable for more situations.

Clinical Experiment

In all, 84 patients with stroke were screened for the study, 53 patients with stroke were excluded because they met exclusion criteria, and 7 declined to participate. Hence, 24 patients with stroke were recruited. They were randomly allocated into the Stomp Joy + PT intervention group or the PT-only intervention group by picking a sealed envelope. Among the participants in the Stomp Joy + PT intervention group, 2 patients did not complete the full study. One of the patients discontinued because they fell down during training with Stomp Joy, although the patient was unharmed. One of the patients dropped out because of personal issues unrelated to any adverse effects of Stomp Joy. None of the patients who participated in the Stomp Joy intervention suffered from any adverse effects that would be likely to result from VR, such as dizziness or disorientation.

None of the baseline characteristics differed significantly between the two groups (Table 3). The Fisher exact test was performed for sex composition, type of stroke, and lesion side of the experimental group and control group, and 2 independent-sample *t* tests were performed for age, height, and weight. The results showed that there was no significant difference in height (*P*=.19), weight (*P*=.52), age (*P*=.53), or disease duration (*P*=.93) between the two groups. The Fisher exact probability method showed no significant difference in gender composition between the two groups (*P*=.39). The general statistics of the patients are shown in Table 3.

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Table 3. Baseline characteristics of the patients with stroke (N=22).

Outcome	Control group (n=11)	Experimental group (n=11)	*P* value[a]
Male, n (%)	8 (73)	5 (46)	.39
Hemorrhage, n (%)	6 (55)	5 (46)	.76
Right-side lesion, n (%)	9 (82)	10 (91)	.61
Height (cm), mean (SD)	167.09 (4.46)	162.72 (5.97)	.19
Weight (kg), mean (SD)	67.27 (7.93)	60.54 (9.39)	.52
Age (years), mean (SD)	52.82 (12.29)	57.55 (14.22)	.53
Time since stroke (months), mean (SD)	4.91 (3.21)	3.81 (3.60)	.93
FMA-LE[b], mean (SD)	18.36 (5.52)	22.64 (4.61)	.11
MBI[c], mean (SD)	70.91 (16.10)	70.45 (17.39)	.51
BBS[d], mean (SD)	35.82 (10.32)	37.73 (8.79)	.62
SLS[e] time (s), mean (SD)	1.09 (0.61)	1.04 (0.61)	.86

[a]All *P* values were for paired *t* tests except for gender (male or female), for which *P* value was for Fisher test. Statistically significant at $P<.05$.

[b]FMA-LE: Fugl-Meyer Assessment for Lower Extremity.

[c]MBI: Modified Barthel Index.

[d]BBS: Berg Balance Scale.

[e]SLS: single-leg stance.

As determined by the Shapiro-Wilk test, the FMA-LE, MBI, BBS, and SLS time data of each group obeyed normal distribution ($P>.05$). Repeated-measures ANOVA with a Greenhouse-Geisser correction showed a significant effect of time on FMA-LE ($P=.001$; $\eta p^2=0.69$), MBI ($P<.001$; $\eta p^2=0.82$), BBS ($P<.001$; $\eta p^2=0.93$), and SLS time ($P=.03$; $\eta p^2=0.41$) (Table 4). These results indicate that the experimental group and control group improved LE physical function, MBI, BBS, and SLS time after 2 weeks of intervention. However, no significant group effects were found for FMA-LE, MBI, or BBS, while a significant group interaction was found for SLS time ($P<.001$; $\eta p^2=0.82$) (Table 4). These results indicate that the experimental group significantly improved more in SLS time than the control group. The time-group interaction also showed significant effects for FMA-LE ($P=.006$; $\eta p^2=0.55$), MBI ($P=.001$; $\eta p^2=0.66$), BBS ($P=.004$; $\eta p^2=0.59$), and SLS time ($P=.001$; $\eta p^2=0.68$) (Table 4). This suggests that the experimental group had better outcomes after the intervention than the control group.

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Table 4. Main effect of time, group, and time-group interaction of the intervention on the outcome measures by repeated-measures analysis of variance with a Greenhouse-Geisser correction.

Parameters	Study group		*P* value[a] (ηp^2)		
	Control group, mean (SD)	Experimental group, mean (SD)	Time	Group	Interaction
FMA-LE[b]			.001 (0.69)	.06 (0.32)	.006 (0.55)
Week 0	18.36 (5.52)	22.64 (4.61)			
Week 2	19.82 (5.51)	25.73 (4.45)			
MBI[c]			<.001 (0.82)	.76 (0.01)	.001 (0.66)
Week 0	70.91 (16.10)	70.45 (17.39)			
Week 2	75.00 (15.17)	80.00 (16.59)			
BBS[d]			<.001 (0.93)	.38 (0.08)	.004 (0.59)
Week 0	35.82 (10.32)	37.73 (8.79)			
Week 2	38.00 (10.61)	43.45 (9.30)			
SLS[e] time			.025 (0.41)	<.001 (0.82)	.001 (0.68)
Week 0	1.09 (0.61)	1.04 (0.61)			
Week 2	1.53 (0.71)	3.63 (1.79)			

[a]Statistically significant by repeated-measures analysis of variance.

[b]FMA-LE: Fugl-Meyer Assessment for Lower Extremity.

[c]MBI: Modified Barthel Index.

[d]BBS: Berg Balance Scale.

[e]SLS: single-leg stance.

Discussion

Implications and Future Studies

Because there is damage in the advanced central nervous system in patients with stroke, the normal synaptic connections are broken and the low central nervous system is not under control, resulting in the loss of muscle strength and coordination, body balance dysfunction, impaired lower limb movement function, and other symptoms [38]. Based on the depth camera somatosensory interactive technology, the virtual reality game can realize the natural interaction between the user and the virtual environment, which can combine spatial vision, perception movement, task concept, motion control, and feedback information to improve the posture control and balance function of patients with stroke [15,39,40].

Stomp Joy is a depth camera–based, task-specific virtual reality rehabilitation game developed to facilitate motor recovery after stroke. At the beginning of the game, patients need to observe the action, which contributes to motor recovery through mirror motor neuron activation [41], as viewing the movements demonstrated on the screen might also help with functional improvement. In addition, this somatosensory interactive virtual reality technology allows the patient to control the training independently by using their own gestures to control the interface and the game process. Thus, it might raise the user's awareness of their own motion. Adapting the intervention to patients' current functional levels and providing appropriate therapy programs can lead to patients' functional improvement. The physical therapist can adjust the stimulus according to the patient's functional level and the feedback in Stomp Joy to motivate patients to engage more. Training is considered meaningful when there is a good relationship between the patient's movements and the outcome on the system.

Rehabilitation goals should also be considered. Stomp Joy is able to gradually adjust the difficulty level according to the patient's progress, which is a valuable feature. On the other hand, the physical therapist, who is in direct contact with the patient, could combine the training performances and the practice date provided by Stomp Joy to design new sets of individualized tasks for patients. Hence, we made sure that patients with stroke could continue to be optimally challenged as the training continues. We also created a safe testing and training environment for patients based on the depth camera's virtual reality interactive technology. Because of its unique training format, this intervention is more attractive to patients compared with traditional training, which in turn improves patient initiative in rehabilitation and encourages patients to actively participate in rehabilitation.

Another area of concern in the real-world setting is how to deliver the treatment safely. It is always important to ensure the patients' safety when applying a new training system. While Stomp Joy performed adequately, 1 patient fell during treatment. Afterward, we placed a frame beside the patients, and no other patients fell during treatment with Stomp Joy. The motor function of patients who are recruited into the training should also be strictly monitored, and the physical therapist should supervise the patients during the entire treatment.

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According to the semistructured interviews of physical therapists and physiatrists, it would be better to add a records module of patients' training data in the Stomp Joy system. Additionally, more games should be designed to avoid monotony during long-term training. To improve the whole system and its application in the clinic, further studies are needed.

Limitations

There are several limitations to our study. First, different experimental protocols using different intervention times in the two groups might have caused the inconsistency in the results. However, the goal of the experiment was not to prove that treatment with the Stomp Joy VR game is better than traditional physical therapy. The goal of the experiment was to introduce the newly designed depth camera–based VR game, Stomp Joy, and to see if the new style of treatment, together with traditional therapy, could bring any progress to the patients. In addition, there have been many studies that have applied VR games for different amounts of time [42]. In the near future, an investigation focused on the duration of time with a consistent protocol will be needed in order to establish an appropriate rehabilitation protocol. Second, although the accuracy of the depth sensor (PrimeSense 3D Awareness Sensor with infrared projectors combined with standard RGB and infrared CMOS image sensors) in the Kinect system was discussed in a previous study [14], in which the maximal static error was 2.76° and the correlation coefficient of the dynamic track was 0.9917 when tracking lower extremity movement, we did not study the accuracy of the tracking of lower extremity movement in this game system, for which a further study is needed.

In the clinical experiment, the assessments were restricted to functional outcomes (FMA-LE, MBI, and BBS) and objective measurements (SLS time). It was better to analyze the improvement separately according to different side impairments, but in this pilot study, the majority of patients had lesion sides on the right (Table 3). More participants need to be recruited to see whether unilateral impairment could influence the functional outcomes. This study would have been improved by using more objective measurements, such as range of motion and strength. It also would have been better to evaluate the kinematic data recorded in real time during the Stomp Joy intervention. In addition, factors such as cognitive function, flow experience, motivation, and depression were not appraised in the clinical experiment, which is common when examining patients with stroke.

Conclusion

This study described a pilot clinical trial of a depth camera–based, task-specific virtual reality rehabilitation game called Stomp Joy. Stomp Joy was proven to be a feasible and safe rehabilitation tool to enhance lower limb motor function and balance among patients with stroke. Stomp Joy can also encourage the patient's functional development, improve immersion, and motivate further rehabilitation by providing meaningful play, optimal challenge, and flow experience. However, because this was a pilot study that was underpowered to show superiority of one treatment over another and had several limitations, further powered randomized controlled trials are now needed before recommending routine use of Stomp Joy in order to confirm these findings by recruiting a larger sample size.

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Authors' Contributions

YX and MT contributed equally to this article. YX and MT conceived of the original idea and designed the study. WM did the experimental studies and drew the figures. YX did the data analysis and data interpretation and wrote the first version of the manuscript. Both W-KM and WH contributed to the final version of the manuscript. YX and MT collected clinical data. YL contributed to the manuscript draft and data analysis. ZC conceived of the original idea, designed the study, and supervised the project. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

Conflicts of Interest

ZC is the copyright holder of the depth camera–based game system. The remaining authors declare no conflicts of interest.

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Abbreviations

ANOVA: analysis of variance
BBS: Berg Balance Scale
CMOS: complementary metal-oxide semiconductor
FMA-LE: Fugl-Meyer Assessment for Lower Extremity
IMI: Intrinsic Motivation Inventory
LE: lower extremity
MBI: Modified Barthel Index
PT: physical therapy
SLS: single-leg stance
VR: virtual reality

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Original Paper

Application of Eye Tracking in Puzzle Games for Adjunct Cognitive Markers: Pilot Observational Study in Older Adults

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Abstract

Background: Recent studies suggest that computerized puzzle games are enjoyable, easy to play, and engage attentional, visuospatial, and executive functions. They may help mediate impairments seen in cognitive decline in addition to being an assessment tool. Eye tracking provides a quantitative and qualitative analysis of gaze, which is highly useful in understanding visual search behavior.

Objective: The goal of the research was to test the feasibility of eye tracking during a puzzle game and develop adjunct markers for cognitive performance using eye-tracking metrics.

Methods: A desktop version of the Match-3 puzzle game with 15 difficulty levels was developed using Unity 3D (Unity Technologies). The goal of the Match-3 puzzle was to find configurations (target patterns) that could be turned into a row of 3 identical game objects (tiles) by swapping 2 adjacent tiles. Difficulty levels were created by manipulating the puzzle board size (all combinations of width and height from 4 to 8) and the number of unique tiles on the puzzle board (from 4 to 8). Each level consisted of 4 boards (ie, target patterns to match) with one target pattern each. In this study, the desktop version was presented on a laptop computer setup with eye tracking. Healthy older subjects were recruited to play a full set of 15 puzzle levels. A paper-pencil–based assessment battery was administered prior to the Match-3 game. The gaze behavior of all participants was recorded during the game. Correlation analyses were performed on eye-tracking data correcting for age to examine if gaze behavior pertains to target patterns and distractor patterns and changes with puzzle board size (set size). Additionally, correlations between cognitive performance and eye movement metrics were calculated.

Results: A total of 13 healthy older subjects (mean age 70.67 [SD 4.75] years; range 63 to 80 years) participated in this study. In total, 3 training and 12 test levels were played by the participants. Eye tracking recorded 672 fixations in total, 525 fixations on distractor patterns and 99 fixations on target patterns. Significant correlations were found between executive functions (Trail Making Test B) and number of fixations on distractor patterns (P=.01) and average fixations (P=.005).

Conclusions: Overall, this study shows that eye tracking in puzzle games can act as a supplemental source of data for cognitive performance. The relationship between a paper-pencil test for executive functions and fixations confirms that both are related to the same cognitive processes. Therefore, eye movement metrics might be used as an adjunct marker for cognitive abilities like executive functions. However, further research is needed to evaluate the potential of the various eye movement metrics in combination with puzzle games as visual search and attentional marker.

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KEYWORDS

eye tracking; puzzle games; aging; cognitive assessment; cognition, attention, executive functions, visual search, fixations

Introduction

Background

From finding certain items among many others (eg, a book in the library) to navigating, visual search is a necessary behavior in our daily life. Visual search is the ability to find and locate target objects in a pool of stimuli [1,2]. To elaborate the large amount of visual information, frequent eye movements termed saccades are performed until the correct target is fixated [3]. Different stimuli compete for attention to get selected for a fixation. Some selective attention models claim that low-level visual features such as intensity, color, and edge orientation increase the probability of gaining visual attention and influencing eye movements such as saccades or fixations. Saccades and fixations are not only related to attention but also to other cognitive functions like memory [2,4,5].

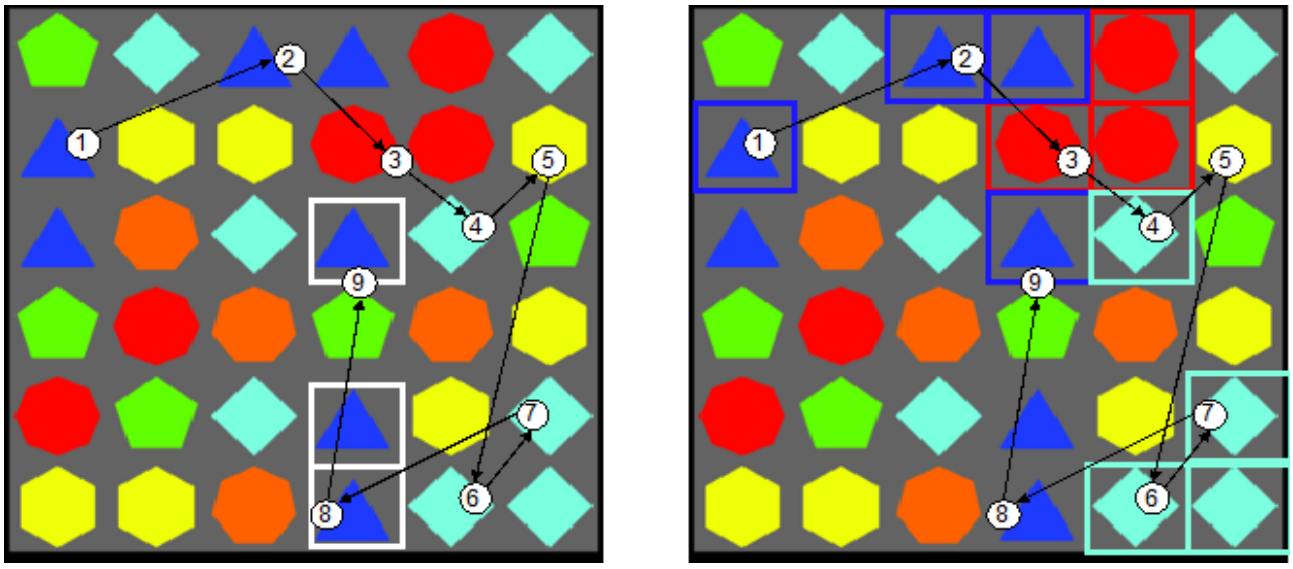
Visual Search in Aging and Neurodegenerative Diseases

Visual search strategies change in the course of aging and are also affected by age-related neurodegenerative diseases. When compared with younger adults, older adults show decreased peripheral target detection [6]. During memory retrieval, eye movement supports the reinstatement of spatial locations of stimuli and their temporal order during encoding. During aging, gaze reinstatement can support memory performance as compensation when task demands are too high. But this compensation is only possible up to a certain extent after which further compensation is impossible [2]. Older adults have shown worse performance than younger participants in visual search tasks, including longer reaction times and more time spent per item [7]. The absence of targets within a trial as well as an increasing number of distractors have been shown as responsible factors for the decreased performance in older adults [8]. This decreasing efficiency in visual search tasks in older adults can be explained by a decline in visual processes and executive functions [9]. In pathological aging (ie, dementia), saccade abnormalities are correlated with the level of cognitive impairment [10].

Puzzle Games as a Tool for Investigating Visual Search

Visual search also plays a key role in solving specific computerized cognitive trainings such as puzzle games [11]. Puzzle games have been used as training tools in health sciences [12-14], and recent research suggests their potential as digital markers of cognitive and motor dysfunctions [15,16]. Well-known puzzle games are tile-matching match-three (TMM3) [17] and flow free [18]. In TMM3 games, participants remove as many tiles as possible in a certain amount of time [17]. Participant must perform visual search to identify where 3 identical puzzle pieces could line up by moving one piece by one place in a grid horizontally or vertically. A typical TMM3 puzzle is ideal for investigating visual search, as the participant has to track the location of multiple static items which requires focused and deliberate searching for target items and visuospatial processing [13,15]. A set of distractor patterns are typically present within each TMM3 puzzle (Figure 1). The filtering of distractor elements has long been established as key in the selection of visual search targets [19]. Observing participant gaze fixations toward distractor patterns may provide additional information on the cognitive processes necessary for solving these tasks [15,20]. In this study, we used a Search and Match Task (SMT) based on a TMM3 video game, a cognitively demanding puzzle game, which has also been demonstrated in other studies [15,21].

Figure 1. Target pattern (left) and distractor patterns surrounding target pattern (right). Areas of interest for eye tracking are marked, and theoretical gaze path is depicted.



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Visual Search in Puzzle Games

Visual search tasks investigate how we find a defined item in a complex environment. In such tasks, participants are typically asked to search for a certain target among distractor items. These target items are defined by one or several distinct features such as shape or color [1]. During visual search three subprocesses are distinguishable: initiation of search, overt search of visual display, and verification of target [3]. The overall process of visual search can be described as either efficient or inefficient; which search type is used depends on the environment. In an efficient search process, the target is easy to identify, and items can be processed in parallel. The inclusion of additional distractors has no effect on the reaction time. In an inefficient search process, target and distractors show similar visual features, and the target is not more salient than the other items. In this case, attention must be allocated to single items in a serial way until the target is found. The addition of distractors increases reaction time [9,22,23]. Certain kinds of puzzle games can be seen as inefficient visual search tasks, where color and shape of items drive attentional search processes [11,24].

During a visual search task, different strategies can be used to allocate attention, depending on the task demands. One way to investigate the type of strategy is assessing the number of eye movements. When participants receive no feedback about task performance, they tend to use similar search strategies across different types of tasks but different amount of saccades can be measured. In an efficient search task, fewer saccades are performed than in an inefficient search task. If feedback about performance is provided, participants are able to adapt strategies to fit the demands of the current task [25]. Eye movements are also influenced by style of stimuli presentation. When stimuli are arranged in grid-like patterns, visual search tasks lead to systematic scanning behavior. There are larger amount of horizontal than vertical saccades during the task, even if the grid-like pattern is heavily distorted (ie, items are displayed irregularly and not on every junction of the grid) [26]. Further research has shown that the stage of verification process takes longer when the grid-like pattern is more distorted while search initiation and scanning time are not affected [3].

Performance in visual search can be increased by the repeated use of puzzle games in the course of a training [21]. Additionally, puzzle games might serve as assessment tools for visual search impairments in patients with neurodegenerative diseases. One study on patients with mild dementia due to Alzheimer disease (AD), for example, reported impairments in shifting attention as well as in the ability to take advantage of visual cues in a visual search task, visible in prolonged reaction times [27].

Eye Tracking

In visual search tasks, end-of-trial reaction times are commonly assessed but they provide only limited information about how search processes evolved across the trial [20]. One possibility for gathering additional data during visual search tasks is with the use of eye tracking. Eye tracking refers to the process of using an eye-tracker device to track the point of gaze or eye movement of a person. Among other data, it provides gaze coordinates of the user as they search and scan the environment for a certain kind of stimuli [28]. Compared with simple reaction time measurements, eye-tracking data provide insight into visual searching behavior (eg, which item was attended, how long, and when). Therefore, eye-tracking data are useful for understanding fundamental attentional processes (involved in visual search) and strategies [20,28]. Fixations and saccades are commonly analyzed measurements to understand visual attention from eye-tracking data. Fixations are moments when eyes fixate on an object to extract and encode information. The most widely used fixation-based metrics are number of fixations, number of fixations on area of interest, fixation duration, and fixation density. A longer duration of fixation indicates deeper processing of the stimuli and is correlated to high cognitive workload. Saccades are rapid eye movements between fixations. Saccadic metrics include number of saccades, saccadic amplitude (distance), and saccadic duration. Scan paths are a complete description of saccade-fixate-saccade sequences. In video games, eye-tracking data can be used to assess usability and effects of game design [29,30]. Other possible eye-tracking metrics are smooth pursuit, pupil dilation, and blinking. Smooth pursuit movements are slower voluntary movements of tracking dynamic stimuli related to working memory and attention; they have been reported as a diagnostic tool for mild traumatic brain injury [31]. Pupil dilation mirrors cognitive workload and is related to attentional cognitive processes. During the assessment of pupil dilatation, luminance must be controlled because of its effect on pupil diameter, which is stronger than the effect of changes in cognitive workload [32,33]. Blinking has been related to cognitive control [33] and workload [34].

Eye tracking has been used for the assessment of different cognitive processes [35]. It shows potential as a tool to track disease progression, assessing the interplay of both motor and cognitive functions [10]. In a review of eye movements in AD, the authors conclude that patients with AD have different eye movement patterns compared with healthy older adults [36]. The prominent oculomotor features of patients with AD are saccadic intrusions and fixation instability, which are explained by the impairment of saccade pathways in AD. Visual exploration studies have shown that saccades are shorter and fixations are longer in patients with AD than in healthy older adults [37]. Also, higher number of fixations are reported in patients with AD during visual search [38], and the extent of saccade abnormalities in dementia is related to the level of cognitive impairment. To use eye movements as digital markers, they must provide replicable results across the short term and be related to disease severity [10]. To assess the possibility of using eye-tracking data as digital markers for cognitive performance in visual search tasks, it is necessary to study the feasibility of eye tracking in such a task in a first step. This study only addressed saccades and fixations from the eye-tracking measures to study the relationship of eye movements and cognition.

Research Questions

The goal of this study was to test the feasibility of eye tracking with puzzle games to obtain adjunct markers for cognitive processes using eye-tracking metrics such as fixations and saccades. To this purpose, we used the SMT combined with a stationary eye-tracking device and conducted a preliminary user

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study in older adults to evaluate the feasibility of the setup and eye-tracking metrics. First, we expected that game completion time is influenced by the number of fixations. Second, we expected a relationship between the fixations and different difficulty levels of the puzzle game. Third, we expected an association between fixations and saccades and assessment scores for cognition and executive function.

Methods

Participants

Healthy older subjects (n=13; 5 women; mean age 70.67 [SD 4.75] years; range: 63 to 80 years) were recruited from another ongoing study at the University Hospital of Old Age Psychiatry and Psychotherapy in Bern. Inclusion criteria were ability to consent in study participation, age between 60 and 85 years, native or fluent German speaker, and normal or corrected to normal vision and hearing. Exclusion criteria were any history of seizure or stroke, traumatic brain injury, smoking, psychotropic medication, severe tinnitus, self-reported left-handedness, and cognitive impairment (Montreal Cognitive Assessment [MoCA] score <26) [39-41]. No compensation for participation was provided. All participants provided written informed consent prior to study onset in accordance with the Declaration of Helsinki. The cantonal ethics committees of Bern and Northwest and Central Switzerland granted the ethics approval for this study (2016-01281).

Neuropsychological Assessment and Game Perception Questionnaires

The study was performed in one session of approximately 40 minutes per participant. The standardized neuropsychological assessments were administered in paper-pencil format prior to the computer-based puzzle task. The neuropsychological tasks were to assess the concurrent criterion validity of their abilities in relation to the puzzle game assessment and keep consistent findings with the study's previous work [11]. The assessment included the German version of the MoCA [39], Trail Making Test (TMT) A and B [42], Snellgrove Maze Test (SnMT) [43], and Lawton Instrumental Activities of Daily Living (IADL) questionnaire [44]. Cognitive health is defined using the MoCA [41], while the Lawton-IADL is a measure of functional impairment. Additionally, the perception of game [45] and the system usability scale [46] questionnaires were administered in paper-pencil format after completion of the computer-based puzzle-game task.

Demographics and neuropsychological assessment scores of the 13 recruited participants are reported in Table 1. All participants were right-handed except one person (ID 2, ambidexter). Table 1 shows that all participants were cognitively (MoCA: 27.69 [SD 1.374], range 26-30; TMT-A: 20.82 [SD 4.05] sec, range 12.10-28.2 sec; TMT-B: 89.87 [SD 35.47] sec, range: 47.05-128.74 sec; SnMT: 30.84 [SD 10.95], range 15.43-52.26 sec) and functionally (IADL: 7.62 [SD 0.65], range 6-8; cutoff <5) [47] healthy.

Table 1. Participant characteristics and demographics.

Subject	Age (years)	Gender	Glasses	MoCA[a]	TMT-A[b] (sec)	TMT-B[c] (sec)	SnMT[d] (sec)	IADL[e]
1	73	m	Yes	26	23.85	173.00	25.53	8
2	72	m	No	27	22.06	108.00	25.86	8
3	66	m	Yes	27	18.18	54.07	__[f]	6
4	80	m	No	26	21.92	85.45	36.12	8
5	71	m	Yes	27	21.80	84.50	52.26	8
6	65	m	Yes	30	17.26	51.15	34.10	8
7	70	f	Yes	29	19.38	118.89	27.48	8
8	68	f	No	27	20.05	85.00	30.95	7
9	76	m	Yes	29	18.51	89.49	17.83	8
10	73	m	Yes	27	21.60	128.74	28.46	7
11	71	f	No	28	25.80	80.00	49.00	8
12	63	f	No	30	12.10	47.05	15.43	7
13	73	f	No	27	28.20	63.00	27.00	8

[a]MoCA: Montreal Cognitive Assessment (max 30).

[b]TMT-A: Trail Making Test A.

[c]TMT-B: Trail Making Test B.

[d]SnMT: Snellgrove Maze Test.

[e]IADL: Lawton Instrumental Activities of Daily Living (max 8).

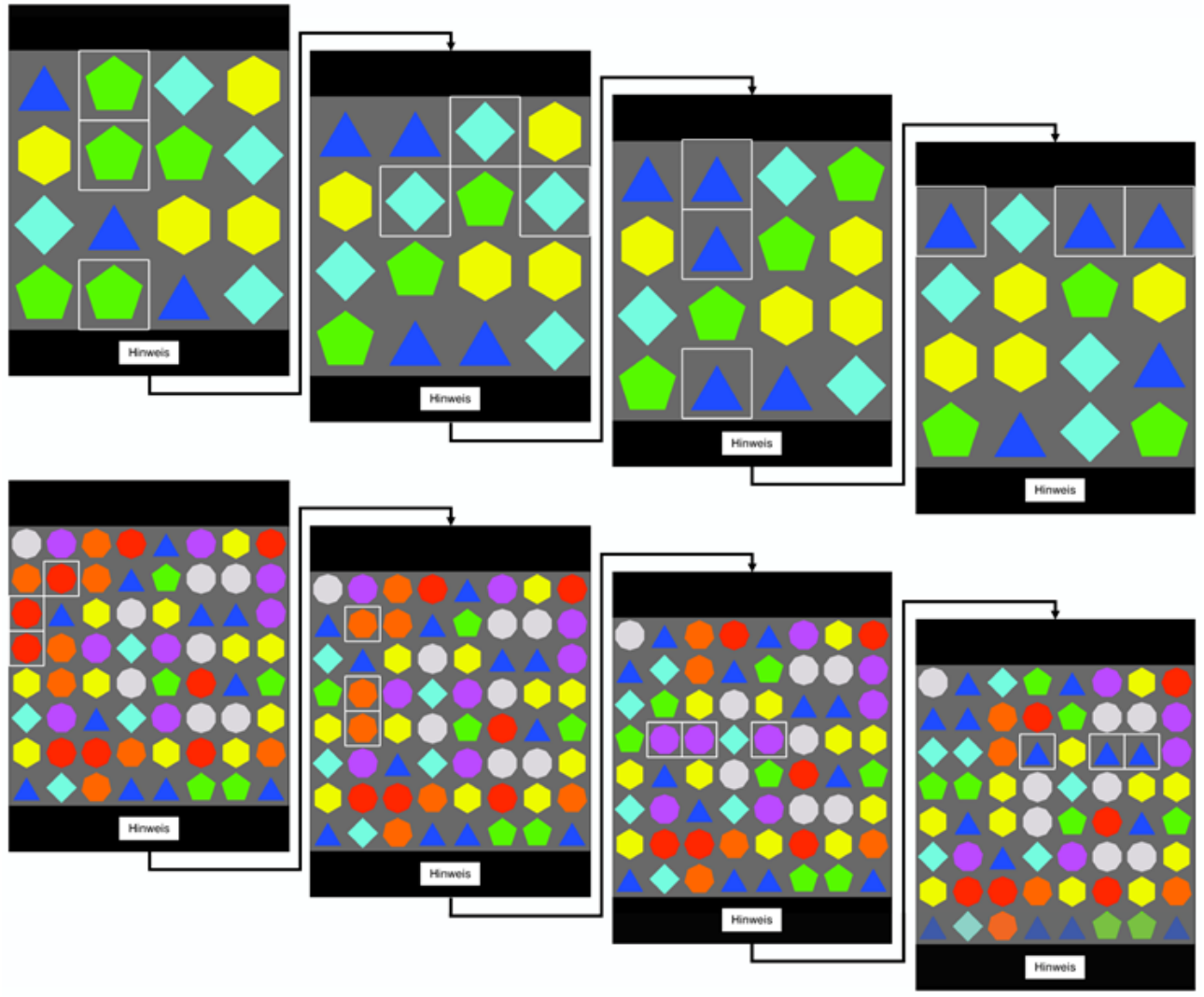
[f]Not available.

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Puzzle Game: Search and Match Task

A custom version of TMM3 SMT game was designed according to the specifications of Chesham et al [15]. The game was built in Unity 3D (language: C#). Modifications to the game were made to include Tobii Pro's eye-tracking Unity plugin (Unity Technologies) and the recording of data, which also included porting the game to a windows platform from the previous iPad app. This pattern-matching visual search task was played on a grid-based puzzle board filled with colored shapes (ie, tiles). The goal of the task was to produce a vertical or horizontal line with 3 identical tiles. This was reached by swapping 2 neighboring tiles (Figure 2). Only moves that produced a target sequence were allowed or else the tiles bounced back to their original place. Level of difficulty was associated with set size and number of unique tiles/gems as defined by Chesham et al [11]. At the beginning of the puzzle game task, 3 training trials were presented. This was followed by 12 difficulty levels selected from a predefined subset that were randomized without any predetermined progression. Each difficulty level was designed to facilitate 4 boards. Each board contained a single-target visual search task (match-3 solution) and was self-terminating (ended as soon as single target pattern was made). Game-based search time, number of hints used, and number of false moves [11] were collected for the 3 training and 12 test levels. Distractor patterns were not controlled but recorded for each level played.

Figure 2. Tile-matching match-three game and step-by-step visual guide for solving each stage of a single 4-step round. In this version of the game, levels were carefully designed so that only one possible solution exists in each step [15].



Experiment and Data Collection

The puzzle game was run on a 13-inch XPS laptop (Dell Technologies) with a Tobii Pro X3-120 (Tobii AB) eye-tracking bar attached below the screen facing upward at approximately the eye level of the participant (Figure 3). Both eyes were recorded in the eye-tracking process. Eye data were recorded at 120 Hz (maximum frequency) and a latency of <11 ms. This served as a corrective set of data for the Tobii Pro. The Tobii Pro software kit used by the Unity plugin would use these data to automatically correct the output data to an advertised accuracy of 0.4° at a rate of 120 Hz, precision 0.24° [48].

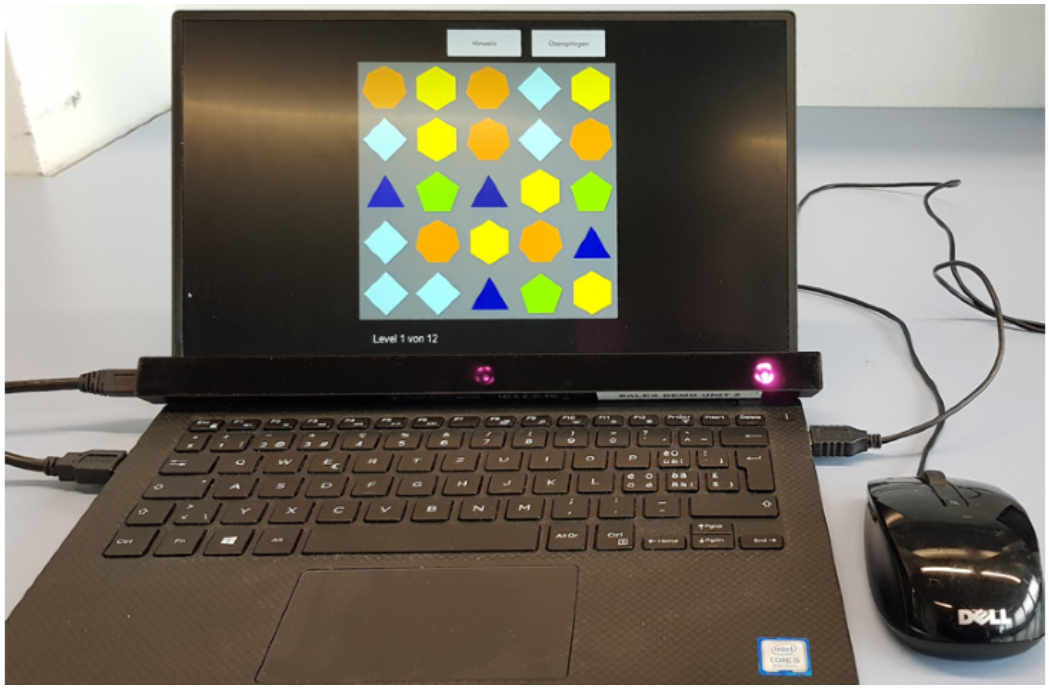
Participants were informed of the procedures in the user study, and written consent was obtained. This was followed by a cognitive assessment, where the MoCA, TMT-A, TMT-B, SnMT, and IADL were administered in paper-pencil format. For the puzzle-game session, participants were first instructed on how to play the SMT. Participants were told that there was

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only one target pattern to match for each board and were shown how to use the hint button.

The eye tracker was then calibrated, during which participants sat upright in front of the screen and a series of red dots appeared in each corner of the screen. After eye tracker calibration, a training block with 3 trials of incremental difficulty was administered (width, height, tiles = 4,4,4; 5,5,5; 6,6,6). In the test block, participants completed the 12 SMT difficulty levels. Players were instructed to complete each puzzle subset to advance to the next puzzle and that they could complete the puzzles at their own pace.

Figure 3. Setup presented to participants during the experiment. Software was loaded onto a Windows laptop with the Tobii Pro angled to face eye level of the participant.



During their play through, eye tracking, mouse data, and puzzle-specific information was automatically recorded by the puzzle software. A summary file was automatically recorded for each participant, which included mouse data at 120 Hz, eye gaze data at 120 Hz, time taken to solve each puzzle, and which puzzle sets were chosen from a set of predetermined puzzles. All data were stored locally on the computer. On completion of the puzzle-game task, perception [45] and usability [46] of the game was collected in paper-pencil format.

Data Analysis

As outcome variables, we calculated saccade distance, saccade duration, number of fixations (average, on target, and on distractor patterns), number of distractors, time for game completion, and visual and effective search time. The raw data were analyzed with Python 3.7 [49] and common libraries like pandas [50] and numPy [51]. Using the timestamps, we matched the content of the different files containing mouse, eye-tracking, and puzzle board data. The mouse data contains all the mouse movements and a flag indicating whether the mouse was clicked or not. The eye-tracking data files (*.xml) provide coordinates of the left and right eye on the screen, computed by the eye-tracking software. For the puzzle data, a summary file with entries for each played move on the SMT was stored. Each move entry in this summary file included the trial number, height, width of the puzzle board, number of unique tile types, move number, time to make the move, false or correct move, and hint use. Time-based game performance metrics were calculated as described in SMT publication [11].

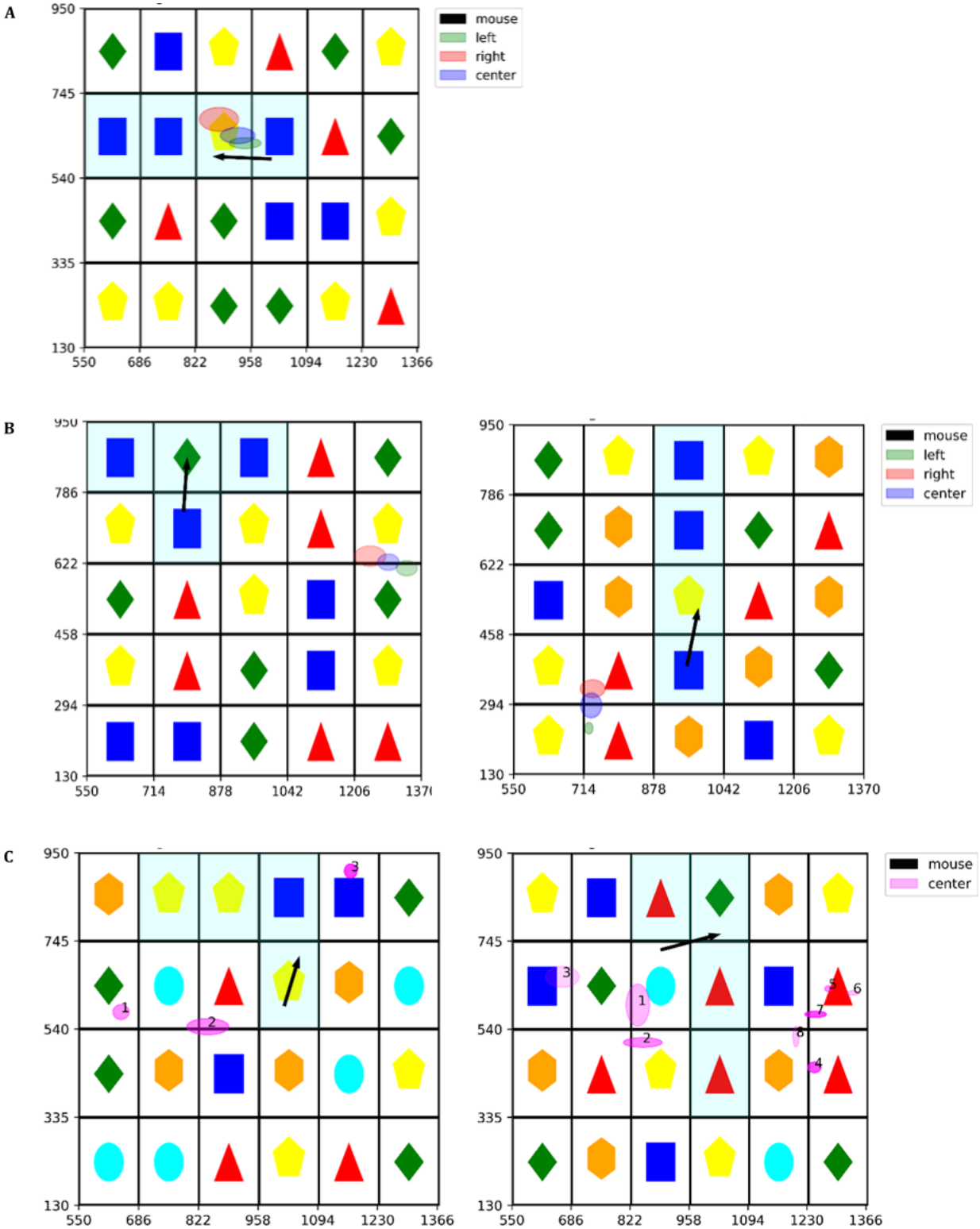
Constraints for selecting fixations from the eye-tracking data:

- Fixation duration threshold had to be at least 100 ms, allowing a balance between theoretical maximum and minimum [52-56]
- Fixations with at least 5 data points available were considered for further analysis
- Points closer than 64 pixels to the previous point in the fixation were considered to segregate the region of interest on the board
- Fixations were discarded if the mean (average) of the left eye's coordinates deviated more than 100 pixels from the mean of the right eye's coordinates, setting a threshold from the centroid of fixation [57]
- Fixations were discarded if the standard deviation of the mean of all points was greater than 100 pixels following the position-variance threshold [28]

For the saccades, we calculated the saccade duration as the difference between the start-timestamp of the current fixation and the end-timestamp of the last fixation. The saccade distance was derived from the Euclidean distance of the center point of the last fixation and the current fixation. The visual search time is calculated as the time from the board initiation until the first fixation on the target (for an example, please see Figure 4 in the results section). Effective search time corresponds to the mouse movement time. Game completion time is the total search time across all boards.

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Figure 4. (A) Fixation of subject (participant ID 3, 66 years, male) while finding the correct match (target). The mouse drag (black) duration was 498 ms. (B) Single fixation on distractor patterns. Left: participant ID 10 (73 years, male, mouse drag duration 674 ms); right: participant ID 7 (70 years, female, mouse drag duration 763 ms). (C) Examples of all fixations on board until target pattern is found. Left: participant ID 3 (66 years, male, mouse drag duration 418 ms); right: participant ID 11 (71 years, female, mouse drag duration 744 ms). X and y axes show pixel values on screen. Black arrow shows movement and direction of clicked mouse. Target pattern (region of interest) is highlighted using transparent turquoise color. Center points of ellipses are the mean of the included fixation data points. Height and width of ellipses are derived from standard deviation in y and x direction of the included points, respectively. Duration of fixation is displayed with alpha value of the ellipses (the more transparent, the shorter the fixation).



Data Exclusion

Eye-tracking data of one participant (ID 9) were excluded due to insufficient data quality for analysis. Four additional participants (ID 2, 5, 12, and 13) were excluded due to the limited number of recorded fixations. The reason for this unusable data for our purpose might be some measurement errors or bad calibration of the eye-tracking system.

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Statistical Analysis

R-Studio version 1.1.463 (R Foundation for Statistical Computing) [58] was used for the statistical analysis. For the 8 participants with a sufficient amount of fixations, Spearman correlations were calculated, as this method doesn't assume normally distributed data and is more robust toward outliers [59]. To help identify any variance accounted for by age and cognition, we performed additional partial correlations between the eye movement metrics and age as well as cognition. Effect sizes were estimated using Cramer *V* [60]. The significance level was set at $P<.05$, as these were exploratory analyses we did not correct for repeated testing.

Results

The eye-tracking bar seemed to provide accurate eye-tracking data with limitations discussed further on. The eye-tracking analysis included data from 8 subjects with sufficient number of fixations.

Game Performance and Eye Movement Metrics

In total, 672 fixations were recorded for the complete dataset of the 8 subjects included in the analysis. Eye-tracking data analysis detected 99 fixations on target patterns and 525 on distractor patterns. Eye movement metrics and game performance scores for the 8 subjects included in the analysis are displayed in Table 2. There may be more than one fixation on targets because each target gem is counted as one target. So, if the fixation is on the edge of 2 target tiles it counts as 2 fixations on targets. Also, there might be multiple subsequent fixations on targets before the mouse was clicked (eg, ID 10 in Table 2).

Correlation analysis showed a tendency toward significance for game completion time with average fixations (r_s=0.66, P=.08), fixations on distractors (r_s=0.68, P=.06), and fixations on targets (r_s=0.69, P=.06).

Table 2. Eye movement metrics and game performance of participants (n=8).

Subject	Visual search time (sec), mean (SD)	Effective search time (sec), mean (SD)	Fixations, mean (SD)	Fixations on distractors, mean (SD)	Fixations on targets, mean (SD)	Saccade duration (sec), mean (SD)	Saccade distance (sec), mean (SD)	Game completion time (sec)
1	__[a]	24.34 (17.37)	15.00 (23.39)	12.33 (18.77)	0 (0)	4.74 (5.51)	258.92 (168.92)	1290.29
3	16.61 (7.21)	40.73 (24.63)	2.40 (1.14)	2.00 (1.00)	0.40 (0.55)	12.62 (12.94)	259.72 (119.93)	1306.78
4	2.48 (0)	21.07 (15.87)	5.83 (6.49)	4.50 (6.83)	0.67 (1.63)	8.41 (5.70)	176.57 (82.54)	1495.21
6	1.59 (0)	5.25 (1.54)	1.00 (0)	1.00 (0)	0.33 (0.58)	5.53 (4.82)	125.25 (5.02)	430.72
7	8.84 (7.97)	19.02 (10.50)	7.20 (7.81)	5.53 (6.93)	0.80 (1.82)	3.81 (4.04)	136.10 (88.40)	1387.22
8	—	15.42 (0)	1.00 (0)	1.00 (0)	0 (0)	—	—	844.75
10	6.65 (4.98)	39.90 (42.71)	22.62 (40.62)	17.92 (35.26)	3.77 (7.70)	4.37 (5.73)	204.84 (141.76)	2180.39
11	14.48 (0)	17.79 (11.62)	5.33 (6.08)	4.56 (5.43)	0.33 (1.00)	3.08 (6.67)	268.10 (178.85)	1555.50

[a]Not available.

Figure 4A shows a single fixation (left, right, and center of left and right eye) of a subject after finding a match and just before dragging the mouse, while Figure 4B shows a single fixation on a distractor pattern. Figure 4C shows multiple fixations and fixation duration on a single board of 2 subjects until the target is found (left, right, and center of left and right eye). Duration of the fixation and number of fixations until the person finds the target match indicate the complexity of the tasks and the inhibition [61] involved in decision making.

Set Size and Eye Movement Metrics

Eye movement metrics for the different set sizes are shown in Table 3. For a constant board height, visual search time increases with increasing width. Correlations between set size and visual search time (r_s=0.18, P=.70), effective search time (r_s=0.35, P=.39), number of fixations (r_s=0.01, P=.98), fixations on distractors (r_s=–0.15, P=.73), fixations on targets (r_s=–0.42, P=.31), saccade distance (r_s=–0.05, P=.91), and saccade duration (r_s=0.24, P=.56) were not significant.

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Table 3. Eye movement metrics for different board sizes.

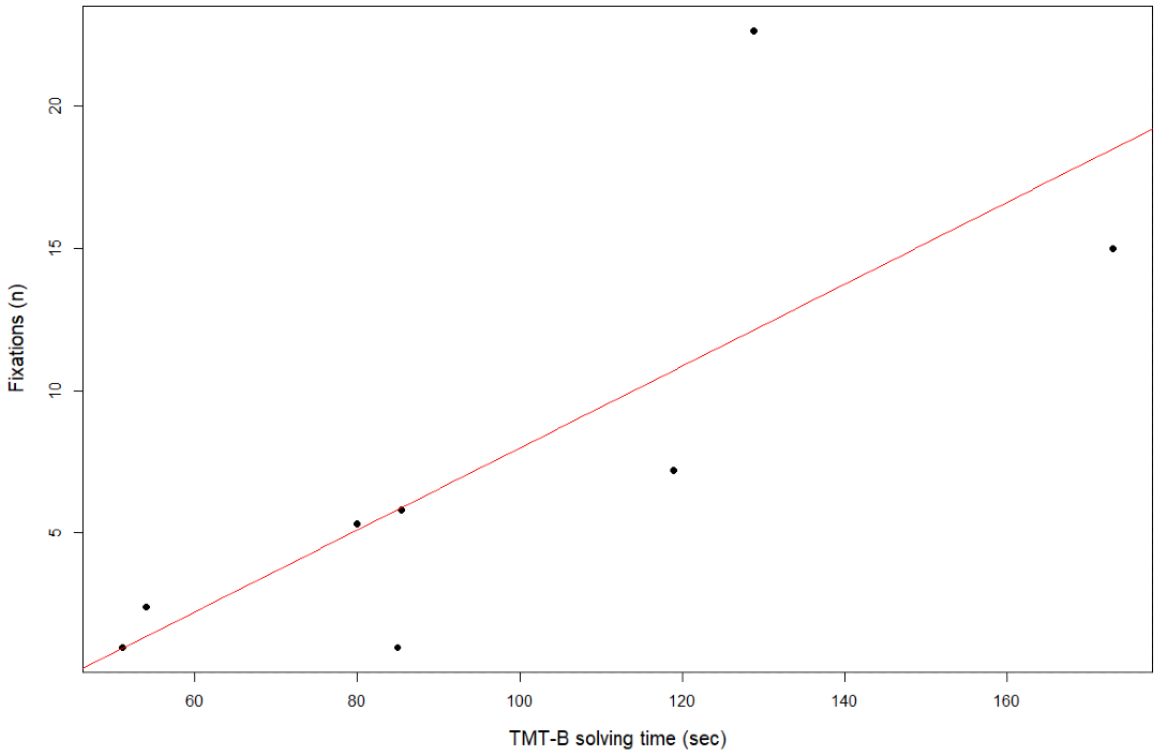
Set size	Visual search time (sec), mean (SD)	Effective search time (sec), mean (SD)	Fixations on targets, mean (SD)	Fixations, mean (SD)	Fixations on distractors, mean (SD)	Saccade duration (sec), mean (SD)	Saccade distance (sec), mean (SD)
4×4	__[a]	—	—	—	—	—	—
4×5	7.58 (3.33)	10.13 (4.20)	0.80 (0.84)	3.40 (2.51)	2.20 (2.39)	5.10 (1.90)	220.40 (105.94)
4×6	8.79 (10.09)	26.66 (24.92)	1.62 (3.07)	5.38 (5.88)	4.50 (5.24)	4.14 (4.58)	197.43 (112.32)
5×4	3.39 (0)	18.30 (13.49)	2.33 (4.04)	14.33 (14.98)	13.33 (13.32)	2.86 (2.81)	171.73 (105.29)
5×5	6.39 (0)	16.43 (15.70)	0.14 (0.38)	3.57 (6.37)	3.29 (6.52)	4.20 (4.68)	301.03 (186.79)
5×6	—	29.36 (9.18)	0	4.00 (2.28)	1.17 (0.75)	6.99 (7.57)	195.54 (124.30)
6×4	8.77 (3.88	40.44 (53.05)	4.00 (10.15)	22.71 (54.37)	19.29 (46.62)	6.90 (8.28)	164.11 (97.49)
6×5	13.28) (10.25)	26.59 (32.77)	1.14 (1.68)	13.86 (22.00)	12.14 (18.75)	2.75 (4.84)	136.39 (93.59)
6×6	5.41 (5.32)	26.6x (12.31)	0.83 (2.59)	11.5x (12.03)	8.17 (9.42)	5.99 (8.10)	211.20 (144.48)

[a]Not available.

Correlation of Eye Movement Metrics and Neuropsychological Assessment Scores

Results of the correlation analyses can be seen in Multimedia Appendix 1. Executive functions measured by TMT-B solving time correlated significantly with number of fixations on distractors (r_s=0.83, *P*=.01, Cramer *V*=0.2) and average number of fixations, (r_s=0.87, *P*=.005, Cramer *V*=0.2, Figure 5), indicating a strong effect [60]. The cognitive subdomain MoCA recall correlated significantly with effective search time (r_s=*–0.85*, *P*=.007), while MoCA attention associated significantly with saccade duration (r_s=0.79, *P*=.03).

Figure 5. Correlation between average number of fixations and Trail Making Test B solving time.



Age as a Covariate

When controlled for age, executive functions measured by TMT-B solving time correlated significantly with number of fixations on targets (r_s=0.97, *P*=.03), average number of fixations, (r_s=1.0, *P*<.001), and effective search time (r_s=0.96, *P*=.04). In addition, functional health measured by IADL associated significantly with average number of fixations (r_p=–0.97, *P*=.03), fixations on distractors (r_p=–0.97, *P*=.03), and fixations on distractors (r_p=–0.99, *P*=.008). However, IADL measurements showed no significant correlation with effective search time (r_p=–0.939, *P*=.06).

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Discussion

The SMT puzzle game has the potential to target the following cognitive domains: learning and memory (working memory), attention (visual search), executive functions (inhibition and flexibility), and perceptual-motor function (visuospatial ability), both as a training and diagnostic tool. The analyzed game metrics after game play (ie, game completion time) have been validated against some of the cognitive domains in a previous study [11]. In this study, we explored the feasibility of supplementing puzzle games with the method of eye-tracking. Eye tracking offers the possibility to observe eye movements in real-time providing additional information about cognitive processes that may go undetected with game testing alone.

Principal Findings

We focused on associations between eye-tracking measures and global cognition, attention executive functions, and game performance measures. The results of this preliminary study indicate an effect of age on number of fixations and found significant correlations between executive functions (TMT-B solving time) and number of fixations, as well as cognitive subdomains recall and attention with effective search time and saccade duration respectively.

Comparison With Prior Work

Eye-tracking devices vary in how eye movements are measured, sampling rate of eye position, accuracy, allowance of head movements, and ease of use. The eye-tracking bar used in this study recorded gaze data at a rate of 120 Hz, which falls within research practices of using 25 Hz to 250 Hz to investigate higher-level cognition [62] allowing free movement of head. While these data are still useful, increasing the fidelity of this data collection may also yield a finer detail of gaze data. The sampling rate of 120 Hz may provide sufficient data points for tracking fixations and barely enough for fixation duration but may fall short for researching saccades [62]. In our sample, the quality of eye-tracking data for some participants was low (ie, few data points were being recorded and were nonsuitable for analysis). Previous research has shown that participant calibrated eye-tracking systems provide higher data quality than operator or automatically calibrated systems. In addition, corrective glasses are known to impair eye-tracking data precision [63]. Both factors could have had a negative effect on data quality in our sample, as many participants wore glasses and we used automatic calibration for eye tracking.

Visual fixation in continuous visual tasks varies in duration (from less than 100 ms to several seconds) [54]. A fixation is an interplay of the visual, oculomotor, and cognitive systems, and hence fixation duration can result from components of inhibition, attention, and cognitive control. The proportion or count of very short fixations can infer the inhibitory influence of the cognitive system [61]. The constraint of 100 ms in our fixation analysis, although on the lower end, gives us the possibility to also include short fixations on distractors wherein the contextual information processed is less. Our analysis resulted in a total of 672 fixations, which led to a low value per puzzle board, considering the puzzle board size and number of participants. Moreover, the total number of fixations was larger than the sum of number of fixations on targets and distractors. This can be explained by fixations on other tile types as well as fixations on edges between targets and distractors that were counted as two fixations. It's questionable if fixations are the appropriate metric for such analysis or if the constraints selected or the region of interest were correct. Our analysis also looks at the saccades in between the fixations; however, saccades are less driven by the cognitive content of the visual stimuli.

The setup used in this study required a mouse as the input device for swapping tiles. To end one board in the puzzle game, a matching target had to be found with a mouse drag. Mouse movement time (ie, effective search time) and visual search time both contributed to game completion time. Lack of association of fixations with game completion time can be attributed to the small set of viable fixation data as well as the motor component involved from the mouse movement.

The difficulty levels in this study were presented in a random order to avoid learning effects. Difficulty level is a number coded for a unique combination of set size and number of types of tiles. Set size effects on search time are well documented. Previous publications from this project [11] report that search time increases with set size, as finding a target pattern in a larger board requires more search and scan time. The previous study [11] also reports that finding a target pattern is less difficult when there are more different types of tiles on the puzzle board. In this study, the average number of fixations, fixations on distractors, and fixations on targets decreases with increasing set size following the trend of set size effect, while visual search time does not follow the same trend.

In the TMT-B task, letters and numbers must be connected alternating in increasing order. Our results revealed significant associations between fixations and measures of divided attention (TMT-B) as well as age. This agrees with findings from earlier studies that reported relationships between TMT-B solving time and visual search measures, attention [64,65], and executive functions (eg, cognitive flexibility [42] and working memory [66]). Visual search and attention are fundamental abilities for solving the puzzle tasks in this study. The association of TMT-B with fixations after controlling for age follows previous research that performance in the TMT task is affected by increasing age [67], and performance on a TMM3 puzzle game is related to measures of selective and divided attention in older adults [68]. The correlations in our data indicate that eye tracking can provide data about cognitive functions, and eye-tracking measures are a possible way to depict these processes.

In the past, several visual exploration studies have investigated eye movements in different populations; however, limited studies are reported for puzzle games. One study with children related eye movements to performance in a puzzle game. They assumed that better performance in the game was associated with different patterns of eye movement than those of lower performing participants. While the results did not allow a clear conclusion regarding fixation duration, it seems lower performers showed higher fixation density in most cases. Fixation intensity also decreased when performance in new levels increased [69]. To our knowledge, there exist no studies performing eye tracking during a puzzle game in older adults.

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In our study, participants with longer SMT-solving times (ie, low performance in this test) performed more fixations on distractors. This could be a sign of more inefficient visual search behavior, which could be related to a decline in executive functions.

Lack of a relationship between general cognition and eye-tracking measures might be explained by the high MoCA scores of our sample. They ranged from 26 to 30 points, which confirms the inclusion of cognitively nonimpaired participants in the study but is probably too small to find correlations. As mentioned in the introduction, other studies with cognitively impaired patients did find a relationship between cognition and eye movements [37,38,69], moderated by the amount of cognitive impairment [10]. Therefore, we assume that a similar study in patients with a diagnosis of dementia might show a relationship between MoCA scores and eye movements.

Limitations

One limitation was that participants wearing glasses had calibration difficulties with the eye-tracking bar, reducing the available participant data. Another limitation was that even after successful calibration, we could not record any fixation on a target in some cases, leading to more sparse data in the visual search time (cells marked as not available in Table 2). The main limitation was the small sample size, which posed a risk of false significant results. Although our participants were healthy older adults with little or no prior game experience, it remains unclear whether our findings can be generalized to a larger population and cognitively impaired persons. But the fact that most significant correlations are related to TMT-B solving time indicates that there exists some relation between executive functions and eye-tracking measures.

Outlook

Clinical

Eye movements are known to be affected in neurodegenerative diseases. In Huntington disease, abnormal eye movements are one of the earliest manifestation of the disease [70]. Previous research has shown that patients diagnosed with dementia or mild cognitive impairment show more and longer fixations on distractor items than healthy participants [38]. Moreover, the visual search strategy of patients with dementia focuses more strongly on areas in the periphery, while healthy older participants focus more strongly on the center of the visual field [71]. The repetition of this study in samples affected by pathological aging could confirm these findings. The combination of eye tracking and a puzzle game provides the option of a cognitive assessment in a game-like fashion, which could be less stressful for the patient. Additionally, this setting is probably not affected by level of education and literacy, which is the case in assessments like the MoCA [72].

Technical

For further research and applying eye tracking during cognitive assessments, a better approach to obtaining eye-tracking data is likely to be found using eye-tracking glasses rather than an eye-tracking bar. There are eye-tracking glasses available that can be used with participants using glasses. This will solve the issue of blocking the eye-tracking bar with participants performing the task on tablets. By placing ArUco markers [73] in the corners of the screen of the tablet app, it would be possible to map recorded eye-tracking data onto the screenspace of the tablet and obtain unobstructed data while also retaining motor function data from the touch display.

Data Analysis

From the data collected, it would also be possible to recreate real-time playback of the session with fixations of the moment showing in overlay. This could provide a valuable visual of the participant's attention to distractors and solutions and avoid any scoring errors in case of doubts.

Conclusions

Eye tracking is a feasible way to collect an extra subset of relevant data. Stationary eye tracking can be used for the recording of visual search in a study of cognitive puzzle games presented on laptops or desktops. However, other eye-tracking devices are preferable for use with tablets, as touch interactions don't block the eye tracker and are more likely to calibrate easier for participants with glasses. The approach shown in this study takes advantage of the eye movement metrics (fixations and saccades) to assess cognitive abilities in a game setup. Fixations show potential as adjunct digital markers for executive functions in puzzle game tasks. These supplementary data can provide additional information to develop cognitive markers. If rigorously tested and evaluated in larger cohorts, it will enhance the specificity and sensitivity of the puzzle game as a diagnostic tool. Further, this study demonstrated that saccades and fixations can be susceptible to aging. Future research should strive to include more age groups and also include cognitively impaired participants to allow generalizability.

Acknowledgments

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Correlations between subject characteristics and eye movement metrics.
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Abbreviations

AD: dementia due to Alzheimer disease
Lawton-IADL: Lawton Instrumental Activities of Daily Living
MoCA: Montreal Cognitive Assessment
TMM3: tile-matching match-three
SMT: Search and Match Task
SnMT: Snellgrove Maze Test
TMT: Trail Making Test

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Original Paper

A Virtual Reality App for Physical and Cognitive Training of Older People With Mild Cognitive Impairment: Mixed Methods Feasibility Study

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Abstract

Background: Therapeutic virtual reality (VR) has emerged as an effective treatment modality for cognitive and physical training in people with mild cognitive impairment (MCI). However, to replace existing nonpharmaceutical treatment training protocols, VR platforms need significant improvement if they are to appeal to older people with symptoms of cognitive decline and meet their specific needs.

Objective: This study aims to design and test the acceptability, usability, and tolerability of an immersive VR platform that allows older people with MCI symptoms to simultaneously practice physical and cognitive skills on a dual task.

Methods: On the basis of interviews with 20 older people with MCI symptoms (15 females; mean age 76.25, SD 5.03 years) and inputs from their health care providers (formative study VR1), an interdisciplinary group of experts developed a VR system called VRADA (VR Exercise App for Dementia and Alzheimer's Patients). Using an identical training protocol, the VRADA system was first tested with a group of 30 university students (16 females; mean age 20.86, SD 1.17 years) and then with 27 older people (19 females; mean age 73.22, SD 9.26 years) who had been diagnosed with MCI (feasibility studies VR2a and VR2b). Those in the latter group attended two Hellenic Association Day Care Centers for Alzheimer's Disease and Related Disorders. Participants in both groups were asked to perform a dual task training protocol that combined physical and cognitive exercises in two different training conditions. In condition A, participants performed a cycling task in a lab environment while being asked by the researcher to perform oral math calculations (single-digit additions and subtractions). In condition B, participants performed a cycling task in the virtual environment while performing calculations that appeared within the VR app. Participants in both groups were assessed in the same way; this included questionnaires and semistructured interviews immediately after the experiment to capture perceptions of acceptability, usability, and tolerability, and to determine which of the two training conditions each participant preferred.

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Results: Participants in both groups showed a significant preference for the VR condition (students: mean 0.66, SD 0.41, t_{29}=8.74, P<.001; patients with MCI: mean 0.72, SD 0.51, t_{26}=7.36, P<.001), as well as high acceptance scores for intended future use, attitude toward VR training, and enjoyment. System usability scale scores (82.66 for the students and 77.96 for the older group) were well above the acceptability threshold (75/100). The perceived adverse effects were minimal, indicating a satisfactory tolerability.

Conclusions: The findings suggest that VRADA is an acceptable, usable, and tolerable system for physical and cognitive training of older people with MCI and university students. Randomized controlled trial studies are needed to assess the efficacy of VRADA as a tool to promote physical and cognitive health in patients with MCI.

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KEYWORDS

virtual reality; elderly; mild cognitive impairment; combined physical and cognitive function; dual task

Introduction

Background

With an aging population across developed countries, ensuring an independent and healthy lifestyle for older people has become a key social issue and a global public health priority [1]. In this regard, the World Health Organization (WHO) has called for more research to identify ways to support the needs of people living with dementia. According to the WHO, “dementia is a syndrome, of a chronic or progressive nature, in which there is deterioration in cognitive function beyond what might be expected from normal aging.” The condition affects memory, thinking, orientation, comprehension, calculation, learning capacity, language, and judgment. Impaired cognitive function is commonly accompanied or preceded by deteriorating motivation, emotional control, or social behavior. At any given time, an estimated 5% to 8% of people aged 60 years and above have dementia; the global total is projected to reach 82 million by 2030 and 152 million by 2050.

Alzheimer disease (AD) is the most common form of dementia and accounts for 60% to 70% of cases [2]. This is often preceded by a predementia stage known as mild cognitive impairment (MCI), which is an intermediate state between normal aging and dementia involving memory deficits [3] and difficulties with language, thinking, and judgment beyond normal age-related changes that may not be obvious in everyday activities. MCI may be amnesic, nonamnesic, or single- or multiple-domain. The amnesic type includes memory loss and is regarded as a transition stage between normal aging and AD [4]. Studies suggest that 5%-20% of individuals with MCI will develop dementia each year [5,6]. Although MCI does not meet the criteria for dementia, it affects healthy aging and indicates a possible need for medical care and treatment. As all forms of degenerative dementia are incurable, treatment focuses primarily on slowing its progression and managing symptoms, typically through a combination of medication and lifestyle changes [7,8].

Physical and Cognitive Training

Among nonpharmacological treatments for MCI, combined physical and cognitive training programs are now gaining wider acceptance as part of the standard treatment for people with symptoms of dementia [5,9-11]. Research suggests that physical and cognitive development are interdependent and closely related [12-17], probably because neurogenesis continues even in older adulthood [18,19], and physical exercise is a key dose-related facilitator of neurogenesis [20,21]. New experiences provided by systematic and intense exercise promote alterations in the brain that can contribute to cognitive rehabilitation. Recent studies have reported improved cognitive performance following combined physical and cognitive activities compared with either one alone [22]. This suggests that simultaneous execution of cognitive and motor tasks may yield the greatest improvements in cognitive function [23]. This *dual task* testing requires significant cognitive control of attentional and executive functions and helps to identify patients with MCI who are at high risk of developing dementia [24]. Dual task training has been tested in dementia intervention studies [23,25,26] and has shown promise in patients with neurological disorders (including MCI) as a means of improving balance [27], gait, and cognitive ability [28]. Preliminary evidence also suggests that direct and indirect interventions targeting cognitive-motor interference can help older people with neurodegenerative diseases [29].

Early diagnosis of MCI, including subtype and stage, facilitates earlier treatment and care that can minimize the onset of neurodegeneration, optimize cognitive and physical functioning, and improve quality of life. Emerging technologies offer novel options for research and practice; among these, virtual reality (VR) is a valuable addition as a safe and controlled environment for user interaction and monitoring of physical activity and cognitive task performance. Manipulation of experimental parameters in VR apps has great potential for new forms of dementia intervention and treatment [30-32].

VR for Combined Physical and Cognitive Training

VR has shown potential as a tool for assessing and training patients diagnosed with dementia and MCI [33,34]. According to recent reviews, VR-based training interventions can be used to improve well-being, cognition, and physical fitness in people with MCI [30,35,36]. Among recent VR systems combining physical training and cognitive training [37,38], the system by Mrakic-Sposta et al [37] involved sequential tasks of riding a bike in a park and avoiding cars while crossing the road to a supermarket. When the system was tested on 10 older patients with MCI and a control group, the results indicated some improvement in cognitive functions, including visual-constructive, visuo-spatial attention, executive, and memory functions, as well as verbal fluency. However, none of the changes was statistically significant [37]. In a more recent

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randomized controlled trial (RCT) [38], a 12-week VR-based physical and cognitive training program led to significant improvements in dual task gait performance among older people with MCI. The physical training elements included Tai Chi, resistance and aerobic exercises, and functional tasks such as window cleaning and goldfish scooping. The cognitive elements included VR games such as buying tickets from vending machines, finding items in a virtual store, and preparing meals as a kitchen chef. Both of these dual task systems for patients with MCI [37,38] were sequential rather than simultaneous. Although closer to everyday situations, these programs also involved multiple cognitive tasks, and some were difficult to compare with standard treatment. In addition, the equipment is expensive and complicated and requires trained specialists to make decisions about system settings and special guidance for participants to ensure efficient training.

On the basis of earlier studies, we designed a simultaneous dual task VR system for physical and cognitive training to support people with MCI. Drawing on clinical findings regarding MCI rehabilitation and new VR technology, we adopted a person-centered approach to develop a user-friendly, immersive VR training system called VRADA (VR Exercise App for Dementia and Alzheimer's Patients). The program content was based on previously tested combined protocols for physical and cognitive therapy [39]. In addition, the VRADA exercises allow for future comparisons with standard care and training protocols.

Design of VR Training Environments

Immersive VR enables researchers to create realistic environments while maintaining a high level of experimental control of essential elements, such as visual and audio feedback and virtual characters. The experience of a virtual body in an immersive virtual environment is similar to the sensations of the biological body [40], and there is a profound link between embodiment and learning [41]. The concept of *presence* refers to the phenomenon of behaving and feeling as if we are actually in the virtual world. This powerful sensation is unique to VR and cannot be created in any other medium. Most people find this magical; unlike *immersion*, where the user is simply surrounded by digital screens, VR enriches immersion and embodiment in a realistic multisensory environment.

Research on the learning impact of embodiment in virtual multimodal environments [42] shows that these settings can facilitate skill transfer when deployed realistically. As embodied navigation and memory are closely linked [43], virtual promenades can compensate for reduced spontaneous motion in older people [44]. In general, embodiment is valuable in these training scenarios because the motivation to experience actions that the situation demands links the user psychologically to the virtual world. VR technology facilitates mixed-ability learning and knowledge transfer and helps participants to interact and collaborate fruitfully through different modalities, and there is evidence that immersive virtual environments enhance training in motor and spatial activities [45,46].

Person-Centered Approach

According to the Alzheimer Society, a person-centered approach is strongly encouraged in dementia care settings, tailoring care to the individual's interests, abilities, history, and personality [47]. This umbrella term is used in different disciplines to describe a model that promotes personal autonomy or self-determination within one's environment. On the basis of self-determination theory, this approach emphasizes the importance of understanding the motivation that drives a person's behavior and the extent of that motivation. The distinction between autonomous and controlled forms of motivation is central to the theory [48,49].

Neurocognitive disorders are commonly associated with symptoms of apathy and are expressed as low motivation and interest in daily activities, which are known to increase the risk of progression from MCI to AD [50,51]. Therefore, encouragement and motivation are important components of every training program. To address the issue of low motivation to exercise and adherence to training among patients with MCI, we incorporated the following motivational techniques [52] in the VRADA training system. These are derived mainly from self-determination theory [53,54].

- Goal setting: choices for exercise duration when starting each training session
- Feedback on behavior: informative or evaluative feedback at the end of each session on training performance (total distance, cycling time, and number of correct answers on cognitive exercises)
- Task crafting (enjoyment): choice of music to enjoy during training
- Self-monitoring of behavior: screen displays indicating time, speed, and distance for monitoring performance while exercising

The VRADA system design is based on human-centered design, which is a systematic method for developing usable products, systems, or services by focusing explicitly on the intended user [55]. The goal is to maximize relevance and usability, which are defined as the extent to which specified users can use a product to achieve specified goals effectively, efficiently, and with satisfaction in a specified context of use. There is evidence that involving users in the design and development of a new system will improve the system's quality by ensuring a more accurate assessment of user requirements and a higher level of user acceptance [56]. This study followed these design principles, strategies, and recommended best practices for formative and feasibility studies [57].

Objectives

This study has 2 main objectives: (1) to describe the formative study of the VRADA system, focusing on how content was developed by working with patients and health care providers and applying the principles of human-centered design and continuous testing (VR1) and (2) to report 2 studies assessing the acceptability, usability, and tolerability of the VRADA system among a sample of university students and a sample of older people with MCI (VR2a and VR2b).

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Methods

Formative Study VR1

In designing the VRADA system, we adopted a human-centered approach by involving patients (as future users) from the early stages, conducting individual interviews to learn about their relevant needs, experiences, attitudes, beliefs, preferences, aspirations, and expectations, and documenting diverse opinions by gender, education level, and cognitive disorder. From the outset of project planning, we also involved health professionals from the Alzheimer Hellas Day Centers, which are responsible for patients' physical and cognitive training in order to consult with them during the design, application, and evaluation phases of the VRADA project.

Study Aim

The aim of this study is to collect information about patients' training experiences, preferences, and expectations to develop a user-centered training system.

Participants and Setting

Patients were recruited for interviews at 2 Hellenic Alzheimer Association Day Centers in Thessaloniki in August 2018. Older people visit these centers voluntarily for neuropsychological assessments, neurological examinations, and case management. A total of 20 patients volunteered to participate in the study (15 women and 5 men; mean age 76.25, SD 5.03 years; age range 69-84 years). In total, 16 had been diagnosed with MCI and 4 with subjective cognitive decline; most patients were retired (mean years of education 11.35, SD 5.76; range 5-18 years).

Assessments

The 2 trained psychologists who worked at the 2-day care centers conducted the interviews using an open-ended questionnaire as a guide. The interview topics were type, frequency, and duration of exercise sessions the interviewee attended at the day care center and whether they engaged in any additional physical activity elsewhere; preferred outdoor exercise environment (scenery, season, time of day, social environment, and music); feedback options while exercising (speed, time, distance, and heart rate); standing bike preferences (familiarity with biking and sitting bike vs upright bike); and cognitive exercises they would most enjoy while biking (memory, attention, and problem solving).

Procedure and Data Analysis

Two interviewers invited older people to participate voluntarily in the study. The first 20 who accepted then signed informed consent forms, and all participants agreed to the use of a voice recorder. Interviews lasted for 30 minutes to 1 hour and were subsequently transcribed verbatim for thematic analysis of each topic or question. All answers were organized in tabular format, and similar answer frequencies were calculated.

Feasibility Studies VR2a and VR2b

Study Aim

In the 2 identical test studies with university students (VR2a) and end users (VR2b), we focused on the acceptability, usability, and tolerability of using the VRADA system as compared with standard care physical and cognitive training.

Participants

A total of 30 undergraduate students (14 males and 16 females) from a physical education and sports science department participated in study VR2a. The mean age of the participants was 20.86 years (SD 1.17). In study VR2b, 27 participants (8 males and 19 females) were recruited from 2-day care centers run by the Greek Association of Alzheimer's Disease and Related Disorders - Alzheimer Hellas. The latter group comprised patients who had been diagnosed with MCI according to the Petersen criteria [58] and were at stage 3 of the disease according to the Global Deterioration Scale [59], with a Clinical Dementia Rating [60] score of 0.5 and exhibiting subjective cognitive decline [61]. They ranged in age from 59 to 85 years (mean age 73.22, SD 9.26 years). Demographic details (educational level, exercise habits, and use of technology) are presented in Multimedia Appendix 1.

Apparatus

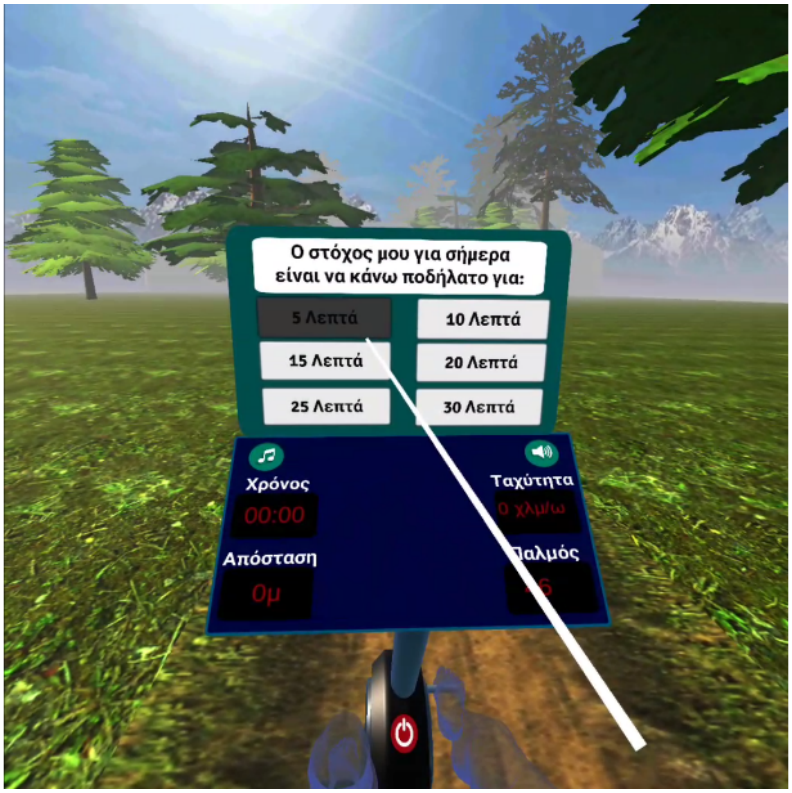
A cycle-ergometer (stationary seated bike type; Toorx, Chrono Line, BRX R 300) was identified as the optimal choice for the exercise apparatus, as it has been proven to reduce user fall risk and facilitate precise control of training conditions. It also meets the requirements of Bluetooth connectivity capability.

Application Description

This section details the functionalities and phases of the VR apps used (a demo video is available in Multimedia Appendix 2). On first running the VRADA app, the user must select the number of minutes they aim to cycle within the virtual environment. As a selection mechanism, we implemented a raycast from the VR controller, allowing the user to select an answer by pointing the ray at the button and pressing the trigger button on the controller (Figure 1).

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Figure 1. User selects the daily goal for the duration of the training session.



At this point, the user can begin cycling on the training bike. During cycling, the user can choose to listen to music from a list of preloaded tracks. The images below (Figure 2) show the math quiz, which asks the user to complete a simple subtraction of 2 single-digit numbers. In this example, as the user answered correctly, the answer is highlighted in green.

Figure 2. User selects the answer to the math calculation exercise.



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After completing the cycling session, the user analytics were displayed in front of the bike, identifying correct and incorrect answers from the math quiz. Finally, the user was asked to evaluate their performance and report any difficulties (Figure 3).

Figure 3. Users' closing screen after completion of the session.



It is important to mention that user data were tracked and exported in an analytics file at the end of each session. This file, containing the answers from the math quiz and user-stated preferences, was also saved to the headset.

Task and Conditions

Each participant was asked to perform a dual task protocol combining physical and cognitive tasks under 2 different training conditions. The physical aspect of the task involved cycling (on a stationary seated bike) for 15 consecutive minutes at a constant speed of 15 km/h. In every trial, the bike workload was initially self-selected by the user and dynamically adjusted by the supervisor in accordance with the exercise protocol. The cognitive task required participants to complete 20 simple numerical calculations (single-digit additions and subtractions) during cycling. In one condition, participants had to execute the cycling task in the lab environment and were asked by the experimenter to perform the calculations orally. In the other condition, participants were required to execute the cycling task in the virtual environment and were asked to perform the calculations that appeared in the VR app using a remote control.

Measures

Personal Innovativeness

Personal innovativeness was measured by using 4 items assessing an individual's general tendency to try out new information technologies [62] adopted from Yusoff et al [63] (eg, I am the kind of person who looks forward to experimenting with new technologies). Responses on a 5-point Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree).

Acceptance

Participants' acceptance of the VRADA app was assessed in terms of 3 factors: perceived enjoyment, attitude, and intended future use. Perceived enjoyment was measured by 6 items that assessed feelings of pleasure while exercising (eg, I really enjoyed exercising in the VR environment) [63]. Responses on a 5-point Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree). Attitudes toward the VRADA app were assessed on the basis of guidelines from planned behavior theory [64] involving 6 bipolar items (eg, pleasant-unpleasant, useful-useless) and scored on a 7-point semantic differential scale. Items assessing intended future use were adapted from a previous study [63] and modified according to the guidelines for assessment of attitudes based on the theory of planned behavior [65]. Three items evaluated the extent to which a person had formulated a conscious plan to exercise in the future in the VR environment (eg, assuming I have access to the system, I intend to use it). Responses on a 5-point Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree).

Usability

The system usability scale (SUS) [66] was used to assess subjective components of usability. The SUS is a self-report questionnaire comprising 10 items—5 positive (eg, I think that I would like to use this system frequently) and 5 negative (eg, I found the system unnecessarily complex). Responses were

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rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Preference

Preference for the 2 exercise protocols was assessed by 8 questions about exercising in the natural or the virtual environment (eg, Exercise was more pleasant..., the numerical calculations were more fun..., time passed quicker..., when exercising with or without the VR mask). Responses were dichotomous, scoring −1 (against VR) or +1 (in favor of VR).

Additional Assessments

A questionnaire and semistructured interviews were conducted to collect additional information immediately following the session. The questionnaire [37] included 9 questions assessing participants' perceptions of using the Oculus Go headset and controller and the environment in terms of (1) usability—pleasantness (4 items; eg, I felt comfortable using the mask; I enjoyed the park ride); (2) usability—learning, (2 items, eg, It was easy to read the numerical questions); and (3) tolerability (3 items assessing dizziness, boredom, and anxiety). Responses on a 5-point Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree). The semistructured interview [67] collected qualitative information to further explore participants' subjective perceptions and feelings regarding reasons to use VRADA (eg, Why would you use the VRADA training system?); expectations after the session (2 items; eg, given the opportunity, would you be willing to use this training system regularly?); usability or utilization (5 items; eg, What difficulties did you encounter during the training session?); usability or learning (2 items; eg, Did you have to ask for help to be able to use the system? Where exactly?); usability or pleasantness (2 items; eg, What exactly did you like most and least?); sense of presence or spatial presence (2 items; eg, Did you feel you had control over the environment?); sense of presence or engagement (2 items; eg, Did you get distracted during exercise? By what?), sense of presence or realism (How did you find the environment—realistic or too artificial?); and tolerability (2 items; eg, Did you feel bad during exercise? When and where exactly?). A detailed interview guide can be found in Multimedia Appendix 3.

Procedure

As volunteers, participants signed consent forms after being provided with an information sheet describing the study requirements and confirming their right to withdraw from the study at any time. In the preparatory phase of the experimental session, participants were told about the procedure and were encouraged to ask questions. They were then equipped with a VR mask and remote control and were allowed some time to familiarize themselves with this equipment. They were then brought to the stationary bike to make seat adjustments and to become familiar with the task, which involved cycling for 2 minutes. Two training conditions were implemented to complete this preparatory phase. The order of the conditions was counterbalanced, with a 10-minute break between the 2 conditions. Finally, after a 5-minute rest, the participants completed the questionnaire and discussed the interview questions with the experimenter. The entire procedure took approximately 60 minutes to complete.

Data Analysis

Quantitative data were analyzed using SPSS Statistics version 21 (IBM Corporation). Summary statistics were calculated for demographic characteristics, and correlations among all examined variables were assessed using the Pearson coefficient. Exercise protocol preference was examined using a single-sample two-tailed t test, using $P<.05$ (two-sided) to determine statistical significance. The qualitative interview data were analyzed using thematic analysis [68], which can offer rich insights into attitudes and beliefs by identifying patterns of ideas or responses. As the discussion topics were based on relevant previous studies, the main themes were predetermined (deductive approach). Second-order themes were analyzed using an inductive approach, allowing the data to determine subthemes.

Ethics Approval and Consent to Participate

The institution's ethics committee granted permission for these studies (approval number: 1557, October 2, 2019). The confidentiality of private personal and health information will be ensured in line with regulations (European Union, EU) 2016/679 (General Data Protection Regulation). Participants were briefed verbally, face-to-face, and provided written information, including the consent form. Where necessary, participants were provided with additional information about the study.

Results

Formative Study VR1

Table 1 summarizes the participants' answers regarding their past experiences of physical activity, along with their preferences and expectations for a VR system combining physical and cognitive training.

The results were presented to the research group, comprising providers of patients' physical and cognitive training, their neuropsychiatrist (extensive clinical and research experience in dementia), exercise psychologists (specialists in exercise motivation), a biomedical engineer, and a computer scientist specializing in computer graphics and extended reality. On the basis of their expertise and the input from patients with MCI, the group made collaborative decisions on the design and content of the first VRADA prototype.

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Table 1. Experiences, preferences, and expectations of patients with mild cognitive impairment regarding a virtual reality training environment.

Topic	Values
Current physical activity	
Type of exercise, n (%)	
Full body exercises	15 (75)
Neck and shoulder exercises	3 (15)
Walking	2 (10)
Frequency of exercise (times/week), mean (SD)	2.70 (1.55)
Duration of exercise (min/training), mean (SD)	53.75 (11.57)
Ideal exercise environment	
Scenery, n (%)	
Forest or park	11 (55)
Seaside	6 (30)
Town	3 (15)
Season, n (%)	
Spring	11 (52)
Autumn	6 (30)
Winter	2 (12)
Summer	1 (6)
Time of day, n (%)	
Morning	18 (90)
Night	2 (10)
Social environment (exercise with other), n (%)	
Yes	18 (90)
No	2 (10)
Natural environment, n (%)	
Sounds of nature	6 (30)
Birdsong	7 (35)
Waves splashing	1 (5)
Other	6 (30)
Music, n (%)	
Soft classic music	9 (45)
Traditional Greek music	5 (25)
No music	6 (30)
Feedback during exercise	
Time, speed, distance, and heart rate, n (%)	
Yes	18 (90)
No	2 (10)
Feedback presentation, n (%)	
Monitor	10 (50)
From training provider	10 (50)
Type of bike	
Familiar with bike, n (%)	
Yes	16 (80)

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Topic	Values
No	4 (20)
Balance on stationary bike, n (%)	
Yes	16 (80)
No	4 (20)
Type of bike, n (%)	
Seated bike	16 (80)
Upright bike	4 (20)
Cognitive exercises	
Number calculations, n (%)	
Yes	15 (73)
No	5 (27)
First letter task, n (%)	
Yes	17 (85)
No	3 (15)
Anagrammatical task, n (%)	
Yes	10 (50)
No	10 (50)
Synonyms-antonyms task, n (%)	
Yes	14 (70)
No	6 (30)
Missing words task, n (%)	
Yes	15 (75)
No	5 (25)
Create sentences task, n (%)	
Yes	18 (90)
No	2 (10)

Building the VRADA Training System

On the basis of information from participant interviews, health professionals from Alzheimer Hellas Day Care Centers, and experts from the exercise psychology research group, the ORAMA-VR team prepared the first prototype, and the biomechanical solutions engineering team incorporated the VRADA software into the bike (Toorx, Chrono Line, BRX R 300). The development procedure was based on continuous testing feedback; that is, each software version was user-tested to inform further development of the prototype. As we felt this might prove burdensome for the intended end users (ie, older people with MCI), university students tested the prototype and provided the necessary feedback.

During this period, a bridge device was used to connect the VRADA software to the bike. Other tasks performed during this period included continuous improvement of the VRADA visual environment, introduction and thorough testing of cognitive exercises, construction of data storage and extraction mechanisms, and adjustments to regulation of real and virtual speeds. Throughout this continuous testing period, student users were asked open questions about specific aspects of the development process—for example, alignment of bike pedaling speed with the VR biking experience. Similarly, when adding cognitive exercises to the VR environment, feedback was collected from a series of trials to improve the design and ensure smooth alignment with the VR biking experience.

System Architecture

The VRADA app was built on top of the ORamaVR MAGES platform [69,70], using the latter's training and interaction mechanics. The MAGES platform is fully customizable and supports educational VR simulations with minimal adaptation. This is accomplished by prototyping the learning pipeline into structured, independent, and reusable segments, which are used to generate more complex behaviors. The architecture supports all current and forthcoming VR head-mounted displays and standard 3-dimensional content generation. The MAGES platform includes the following novel features [70]:

- *Multiplayer with geometric algebra interpolation: custom low-bandwidth and high visual fidelity collaborative modules*. Our geometric algebra framework enables 4 times

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the improvement in reduced data network transfer and lower processor usage.

- *Analytics based on machine learning agents with recommendations*: We used medical experts to train our machine learning agent and constructed a unique trainee profile to make real time suggestions to users according to their level of experience. Our supervised machine learning model is capable of understanding the validity of each action and deciding whether to offer assistance in the form of additional audio-visual guidance.
- *Geometric algebra deformable animation, cutting, and tearing*: The use of quaternions and dual quaternions yielded fast results, with no interpolation problems or other geometric artifacts. Our engine also performs animations with fewer intermediate keyframes, thereby reducing the bandwidth.
- *Editor in VR*: This module allows non-VR experts to develop new modules or scenarios or to modify existing ones in a coding-free environment.
- *Semantically annotated bodies*: The MAGES core includes an advanced mathematical algorithm for physics-based visual techniques that can generate a virtual representation of the body, which is essential for VR physical training.

Virtual Environment

We designed a forest path as a scenery for a relaxing and enjoyable virtual environment. The forest is dynamically generated as the user cycles along the path (Figure 4). We implemented this mechanism to optimize performance, as the app is deployed on a mobile VR headset, and its performance is limited by the onboard graphics chip. In addition, we populated the forest with animals that the user must remember for the purposes of the memory game at the end of the session.

Figure 4. The dynamically generated forest.



Head-Mounted Display

The VRADA app uses Oculus Go as the main VR head-mounted display (Figure 5). Oculus Go is a 3DOF (degrees of freedom) headset with a single 3DOF controller. As a standalone untethered headset, it does not need a desktop connection, and the absence of cables makes the device mobile and ideal for use while exercising.

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Figure 5. The Oculus Go Head-Mounted display.



Feasibility Studies VR2a and VR2b

When the development of the first VRADA prototype reached a satisfactory level, we conducted an early feasibility trial, focusing on acceptability, usability, and tolerability, first with university students and then with the intended end users (Alzheimer Hellas for Alzheimer Association). The efficacy of the final version of the system will be tested in a future RCT (VR3).

Tables 2 and 3 presents the means, SD, Cronbach α, and Pearson correlations for Studies VR2a and VR2b. All scales from both studies exhibited high internal consistency (Cronbach α .71 and .89), with the exception of the SUS, which returned lower (.67 and .68 for VR2a and VR2b, respectively) but still acceptable internal consistency [71].

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Table 2. Descriptive statistics for study VR2a, including Cronbach α and Pearson correlations.

Variables	Study VR2a								Mean (SD)	Cronbach α
	PI[a]	PE[b]	ITU[c]	ATT[d]	SUS[e]	PREF[f]	UP[g]	UL[h]		
PI									3.68 (0.65)	.76
r	—[i]									
P value	—									
PE									4.22 (0.61)	.88
r	0.14	—								
P value	.45	—								
ITU									3.91 (0.95)	.89
r	0.18	0.78	—							
P value	.34	<.001	—							
ATT									6.12 (0.78)	.79
r	−0.00	0.67	0.53	—						
P value	.96	<.001	<.001	—						
SUS									82.66 (9.00)	.67
r	0.13	0.48	0.24	0.47	—					
P value	.49	<.001	.19	<.001	—					
PREF									0.65 (0.41)	.71
r	0.00	0.28	0.44	0.24	0.10	—				
P value	.96	.13	.01	.19	.58	—				
UP									4.33 (0.58)	.58
r	0.31	0.54	0.28	0.35	0.52	−0.04	—			
P value	.08	<.001	.12	.05	<.001	.83	—			
UL									4.40 (0.66)	.59
r	0.21	0.46	0.20	0.43	0.59	0.12	0.43	—		
P value	.25	.01	.28	.01	<.001	.51	.01	—		
TOL[j]									3.94 (0.89)	.61
r	0.19	0.41	0.42	0.27	0.60	0.51	0.56	0.34		
P value	.30	.02	.02	.14	<.001	<.001	<.001	<.001		

[a]PI: personal innovativeness.
[b]PE: perceived enjoyment.
[c]ITU: intention to use.
[d]ATT: attitudes.
[e]SUS: system usability scale.
[f]PREF: preferences.
[g]UP: usability-pleasantness.
[h]UL: usability-learning.
[i]Not applicable.
[j]TOL: tolerability.

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Table 3. Descriptive statistics for study VR2b, including Cronbach α and Pearson correlations.

Variables	Study VR2b								Mean (SD)	Cronbach α
	PI[a]	PE[b]	ITU[c]	ATT[d]	SUS[e]	PREF[f]	UP[g]	UL[h]		
PI									3.86 (0.82)	.87
r	—[i]									
P value	—									
PE									4.43 (0.57)	.81
r	0.36	—								
P value	.06	—								
ITU									4.19 (0.78)	.95
r	0.44	0.82	—							
P value	.02	< .001	—							
ATT									6.17 (1.00)	.74
r	0.05	0.47	0.34	—						
P value	.79	.01	.07	—						
SUS									77.96 (13.40)	.68
r	0.48	0.68	0.70	0.43	—					
P value	.01	< .001	< .001	.02	—					
PREF									0.72 (0.51)	.89
r	0.06	0.23	0.22	0.37	0.10	—				
P value	.73	.24	.26	.05	.61	—				
UP									4.77 (0.52)	.73
r	0.02	0.51	0.42	0.38	0.37	0.52	—			
P value	.89	.006	.02	.05	.05	< .001	—			
UL									4.53 (0.67)	.94
r	0.00	0.27	0.13	0.43	0.28	0.41	0.59	—		
P value	.99	.16	.51	.02	.15	.03	< .001	—		
TOL[j]									4.26 (0.96)	.89
r	0.13	0.26	0.36	0.48	0.47	0.38	0.53	0.33		
P value	.50	.17	.06	.01	.01	.05	.01	.09		

[a]PI: personal innovativeness.
[b]PE: perceived enjoyment.
[c]ITU: intention to use.
[d]ATT: attitudes.
[e]SUS: system usability scale.
[f]PREF: preferences.
[g]UP: usability-pleasantness.
[h]UL: usability-learning.
[i]Not applicable.
[j]TOL: tolerability.

Personal Innovativeness, Acceptability, and SUS

In VR2a, students scored moderately to high on personal innovativeness and intended future use and high on attitudes toward VR exercise and enjoyment. The score for usability (82.66/100) was well above the acceptability threshold (75/100).

In study VR2b, patients with MCI scored moderately to high on personal innovativeness and high on enjoyment, attitude to VR exercise, and intended future use. The usability score (77.96) was also above the acceptability threshold.

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Preferences

A single-sample *t* test was performed to determine whether there was a statistically significant preference for either of the 2 conditions, coding the normal environment as −1 and the VR environment as +1, with the test value set at 0. For study VR2a, the analysis indicated a significant preference for the VR condition (mean 0.66, SD 0.41; t_{29}=8.74; *P*<.001). Similarly, for study VR2b, the analysis indicated a significant preference for the VR condition (mean 0.72, SD 0.51; t_{26}=7.36; *P*<.001).

Pearson Correlations

Pearson correlations between all variables were calculated for the 2 studies (Tables 2 and 3). In study VR2a, innovativeness was unrelated to any of the other variables; acceptance variables were strongly interrelated and moderately related to usability. Finally, preference was most strongly related to intention. In study VR2b, innovativeness was moderately related to usability and to 2 acceptance variables (enjoyment and intention). Acceptance variables were positively interrelated and strongly related to usability. Finally, preference was most strongly related to attitude, but the relationship was not statistically significant.

Evaluation of Headset, Controller, and VRADA Environment

In study VR2a, students' scores were high for the VR gear, VRADA environment, preference, and usability and moderate to high for acceptance variables and innovativeness. In study VR2b, MCI patients' scores were high for the VR gear, VRADA environment, preference, and usability and moderate to high for acceptance variables and innovativeness.

The semistructured interview data regarding usability, sense of presence, tolerability, and expectations are summarized in Table 4. In both groups, most participants reported a preference for the VRADA training system compared with standard care training. Comments in relation to most dimensions of usability were also very similar in both groups, but the MCI patient group reported needing more help when learning how to use the VR equipment. The 2 groups differed in relation to perceived feeling of presence, but engagement and realism (as dimensions of sense of presence) exhibited the same direction. Surprisingly, tolerability was higher among the MCI patients, as was the intended future use of the system.

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Table 4. Summary of interview data: students and patients with mild cognitive impairment.

Main theme	Subthemes	
	Study VR[a]2a (students)	Study VR2b (patients with MCI[b])
Reasons to use VRADA[c]	Because: • ..."VRADA is more pleasant and interesting" (51%) • ..."time passes faster" (31%) • ..."it is less boring" (10%) • ..."it is less tedious" (8%)	Because: • ..."VRADA is more pleasant, beautiful, and interesting" (56%) • ..."time passes faster" (28%) • ..."it is like escaping from reality" (12%) • ..."it improves visibility" (4%)
Expectations	• Future personal use of the system: Yes: 50%; So-so: 33%; No: 17% • System is useful for other populations (young 35%, obese 7%, disabilities 39%, older people 19%)	• Future personal use of the system: Yes: 81%; So-so: 12%; No: 7% • System is useful for other populations (young 18%, everybody 23%, disabilities 41%, people who like to explore nature 18%)

Usability	• Utilization:
	  • General difficulties (no difficulties 64%, VR controller 20%, dizziness 8%, sweat 8%)
	  • Technical problems (none 79%, connectivity 21%)
	  • VR controller use (OK 75%, uncomfortable handle 17%, sensitivity 8%)
	  • VR mask use (OK 89%, blur 11%)
	• Learning to use:
	  • Need for extra help: No 100%
	  • Need more time to understand the system: No 100%
	• Pleasantness:
	  • Most enjoyable parts (environment 68%, music 32%)
	  • Least enjoyable parts (repeated virtual parts 48%, graphics 37%, music 15%)
	  • Feel uncomfortable: No 83%, dizziness 17%
		• Utilization:
		  • General difficulties (no difficulties 63%, VR controller 23%, speed 14%)
		  • Technical problems (none 87%, connectivity 13%)
		  • VR controller use (OK 50%, control and sensitivity 50%)
		  • VR mask use (OK 95%, dysphoria 5%)
		• Learning to use:
		  • Need for extra help: No 78%, Yes (how to start) 13%; Yes (how to use VR controller) 9%
		  • Need more time to understand the system: (No 88%, Yes 12%)
		• Pleasantness:
		  • Most enjoyable parts (environment 92%, animals 8%)
		  • Least enjoyable parts (repeated virtual parts 75%, VR controller 13%, graphics 12%)
		  • Feel uncomfortable: No 95%, VR mask 5%

Sense of presence	• Spatial presence:
	  • Feeling of presence: Yes 23%, So-so 67%, No 10%
	  • Control of the system: Yes 90%, So-so 10%
	• Engagement:
	  • Duration of experience (prefer more 59%, prefer less 41%); distraction of attention: No 68%, cognitive exercises 32%
	• Realism:
	  • Realistic or artificial virtual environment (realistic 3%, so-so 20%, artificial 77%)
		• Spatial presence:
		  • Feeling of presence: Yes 77%, So-so 12%, No 11%)
		  • Control of the system: Yes 88%, So-so 4%, No 8%
		• Engagement:
		  • Duration of experience (prefer more 53%, good 47%), distraction of attention: No 76%, VR controller 12%, cognitive exercises 12%
		• Realism:
		  • Realistic or artificial virtual environment (realistic 34%, artificial 66%)

Tolerability	• Feel bad during training: No 85%, Yes 15% • Feel nausea, dizziness, or other physical symptoms: No 62%, Yes 38%	• Feel bad during training (No 93%, Yes 7%) • Feel nausea, dizziness, or other physical symptoms: No 93%, Yes 7%)

[a]VR: virtual reality.

[b]MCI: mild cognitive impairment.

[c]VRADA: VR Exercise App for Dementia and Alzheimer's Patients.

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Discussion

Principal Findings

The development of the VRADA training system followed the latest proposed recommendations and strategies [56,57] for VR therapeutic and health apps. In line with these guidelines, we focused on the development of the content, VR environment, and system architecture (VR1). In collaboration with patients and health care providers and on the basis of the principles of human-centered design and continuous testing, VRADA incorporated dual task cognitive and physical training for older patients with MCI in a user-friendly VR environment.

The quantitative and qualitative data (VR2) regarding the acceptability, usability, and tolerability of VRADA as a training system are encouraging. As evidenced by the scores across all acceptability dimensions, the system was well accepted by both test groups. Acceptability is a key issue for innovative technology in the treatment schemes of neurodegenerative diseases, especially among the older population [37,38,72,73]. Scores for perceived enjoyment, attitude, and intention to use were well above average, with end users scoring higher than the students' group on all dimensions. The MCI patient interview comments were also very encouraging regarding the future use of VRADA, as they found the system more pleasant and interesting. This positive attitude toward VR among older people aligns with previous research. One systematic review [74] reported evidence that technology is a well-accepted method to provide engaging exercise opportunities to older people, and the high adherence rates can be explained largely by the high reported levels of enjoyment they experience when using these programs.

The SUS results were also very encouraging, indicating that the system exhibited good usability. Developing a usable, immersive VR system for older people at risk of cognitive decline requires careful consideration, and our design followed the latest recommendations [75] for developing similar VR platforms. We involved an interdisciplinary group of experts from the early stages of development and tried to meet basic psychological needs [76] by promoting user autonomy by providing choices. We also addressed their need to feel competent by providing encouragement, feedback, and an easy-to-use system that contributed to enjoyment and satisfaction. As almost half of our older participants were relatively unfamiliar with novel technology use, we provided a short initial training element to familiarize them with VR. However, the end users' comments suggest a need to provide more detailed instructions on using the system; in particular, some additional time might be needed for them to become familiar with the controller.

Simulator sickness, which can be attributed to postural instability or sensory conflict, is often a concern when older people use immersive VR [77]. However, most participants from both groups (93%) tolerated the VRADA training system very well, with no adverse effects (eg, nausea, dizziness, and anxiety) among the patients with MCI, who perceived it as an enjoyable experience. Finally, the correlation results show that personal innovativeness was unrelated to any of the other variables, indicating that the system may be attractive and interesting even for less innovation–seeking users, at least within this sample.

Strengths and Limitations

The VRADA training system is among the first to attempt to transfer standard care, nonpharmacological, cognitive, and physical training as a simultaneous dual task MCI treatment scheme to a virtual environment. According to the literature [78], direct and indirect interventions targeting cognitive-motor interference have shown promise as a means of improving MCI in individuals with neurodegenerative diseases. Although similar previous studies have reported encouraging results [37,38], the dual task training program was sequential rather than simultaneous. Moreover, VR technology training environments such as VRADA provide flexibility in clinical settings because they can be tailored to individual needs and facilitate training in settings that are either impossible or unsafe in the real world. VRADA may also help to increase older people's autonomy and has the potential to reduce the workload of health care professionals dealing with patients with MCI. Finally, VRADA can be combined with other techniques, such as functional magnetic resonance imaging, to track brain functionality in the VR environment. This can provide further valuable insights into the effects of VR [79].

Despite these positive results regarding acceptability, usability, and tolerability, this study has some limitations. As the VRADA training system was only tested in a single session, we cannot conclude that this training would remain interesting and enjoyable after repeated longer sessions, and future studies should explore this issue. It is also important to emphasize that this study was designed to test the feasibility of the VRADA training system but not its efficacy. We intend to test efficacy in the near future in an RCT that will examine whether regular training using the VRADA system results in improved physical, cognitive, and quality of life outcomes.

Conclusions

This study addressed the design of a user-friendly, acceptable, and tolerable immersive VR system for dual task physical and cognitive skills training. Both students and older people with MCI symptoms reported high levels of acceptability, usability, and tolerability when using the VRADA training system, confirming its potential (subject to RCT efficacy validation) as a tool to promote physical and cognitive health among patients with MCI.

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Baseline demographic characteristics: studies VR2a and VR2b.
[DOCX File , 31 KB - games_v9i1e24170_app1.docx]

Multimedia Appendix 2
Video of the virtual reality Exercise App for Dementia and Alzheimer's Patients training environment.
[MP4 File (MP4 Video), 74185 KB - games_v9i1e24170_app2.mp4]

Multimedia Appendix 3
Interview guide.
[DOCX File , 14 KB - games_v9i1e24170_app3.docx]

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Abbreviations

AD: Alzheimer disease
DOF: degrees of freedom
EU: European Union
MCI: mild cognitive impairment
RCT: randomized controlled trial
SUS: system usability scale
VR: virtual reality
VRADA: VR Exercise App for Dementia and Alzheimer's Patients
WHO: World Health Organization

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Review

Serious Games for Improving Technical Skills in Medicine: Scoping Review

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Abstract

Background: Serious games are being used to train specific technical skills in medicine, and most research has been done for surgical skills. It is not known if these games improve technical skills in real life as most games have not been completely validated.

Objective: This scoping review aimed to evaluate the current use of serious games for improving technical skills in medicine and to determine their current validation state using a validation framework specifically designed for serious games.

Methods: We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. A multidatabase search strategy was adopted, after which a total of 17 publications were included in this review.

Results: These 17 publications described five different serious games for improving technical skills. We discuss these games in detail and report about their current validation status. Only one game was almost fully validated. We also discuss the different frameworks that can be used for validation of serious games.

Conclusions: Serious games are not extensively used for improving technical skills in medicine, although they may represent an attractive alternative way of learning. The validation of these games is mostly incomplete. Additionally, several frameworks for validation exist, but it is unknown which one is the best. This review may assist game developers or educators in validating serious games.

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KEYWORDS

serious games; technical skills; ultrasound skills; validity of serious games

Introduction

Point-of-care ultrasound is an important bedside diagnostic tool for various specialties. For internal medicine, it is a relatively new tool, and educational programs have been created in The Netherlands for residents and internists to become competent in ultrasound [1]. Learning to make the right probe movements and constructing a 3D mental image from a 2D screen image may cost time. To assist in training eye-hand coordination with an ultrasound probe, a serious game involving a 3D-printed probe and an underwater game is under development in The Netherlands [2]. However, it is not known if this game will actually improve ultrasound skills (technical skills of probe movements and thereby image optimization) in real practice. To the best of our knowledge, there is no serious game available at this moment for learning ultrasound skills. A review in 2012 showed that some games were available to train other technical skills like laparoscopic psychomotor skills, but none of the serious games had completed a full validation process [3]. In this review, we aimed to explore the current use of serious games for training technical skills in medicine, including

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personal factors of influence while playing these games, and we determined their validation status using a framework for assessing the validity of serious games [4,5]. Knowledge about validation and the current use of serious games for technical skills may provide useful information to develop games for training ultrasound skills.

We have determined the following research questions: (1) Which games exist for training technical skills in medical education or practice? (2) What is known about the validity of these games? (3) Which personal factors influence the performance in these games?

Methods

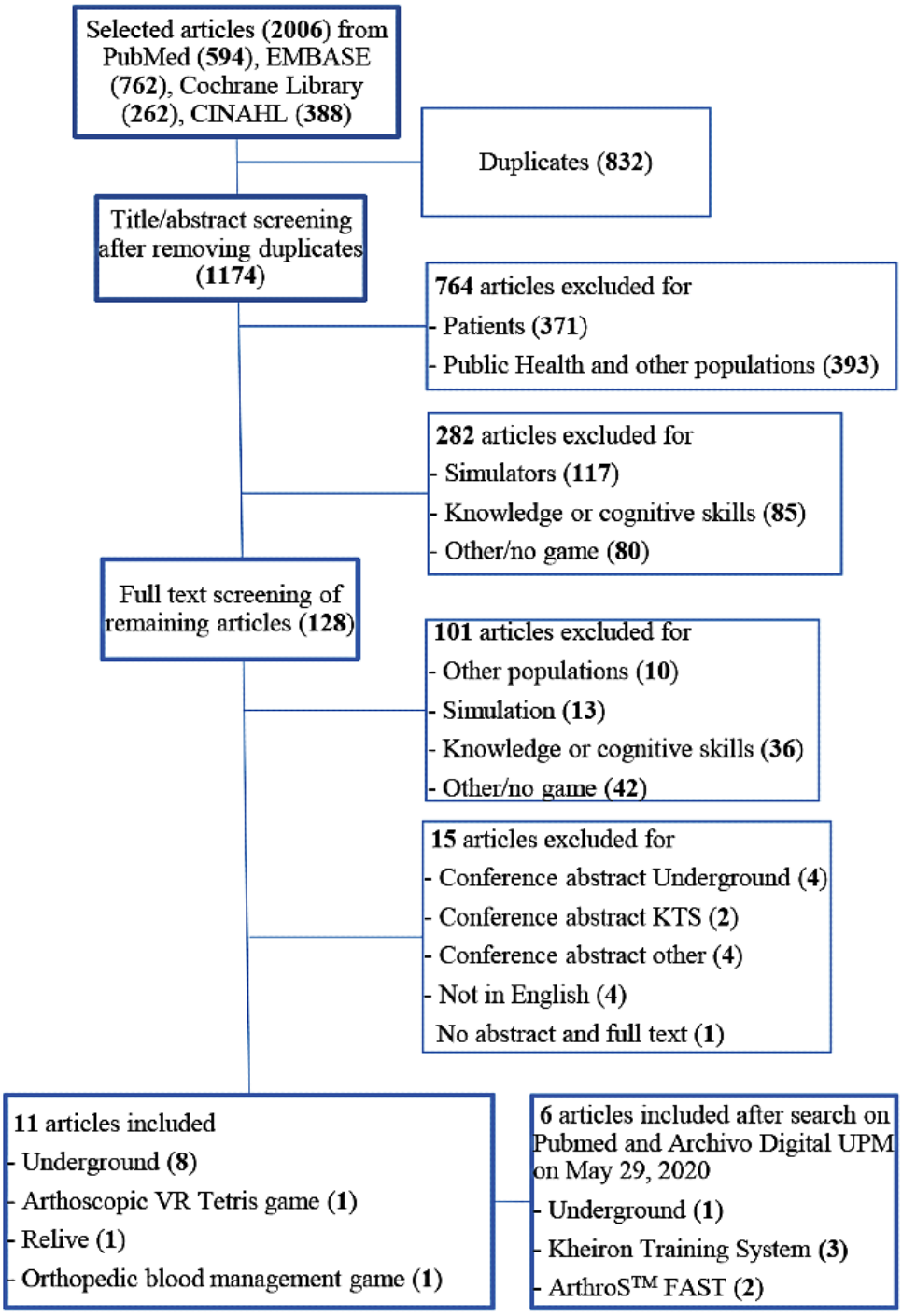
Identification of Relevant Studies

We conducted a scoping review using the recommended items from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extensions for Scoping Reviews (PRISMA-ScR) guidelines [6]. We included original studies investigating serious games for technical skills in health care. Studies were excluded if they (1) evaluated nontechnical skills, such as cognitive skills; (2) included a game that was designed as a therapy for patients or to teach anything other than a medical intervention; (3) did not have full text available; (4) were written in a non-English language; and (5) only described a simulator instead of a serious game.

The databases PubMed, Cochrane Library, EMBASE, and CINAHL were searched on April 9, 2020, using the following terms or abstracts of these terms without limitation of published date: serious game, video game, computer game, education, teaching, training, and skill. This search resulted in 2006 articles (Figure 1). One Author (AbdW) screened all articles and removed duplicates (n=832). After reading the title and/or abstract, another 764 articles were excluded, as they did not concern medical skills, and 282 were excluded for other previously defined reasons (only simulators, describing only cognitive skills, or no game at all). The inclusion and exclusion criteria are presented in Textbox 1. From the 128 remaining articles, the full text was obtained, after which another 101 were excluded for the previously mentioned reasons that could not be determined by the title/abstract. Additionally, we excluded one article because the abstract and full text were not available, four articles because they had non-English text, and 10 articles because they concerned only conference abstracts. The remaining 11 articles were critically assessed, after which six additional articles were found that had not been included in our original search (May 29, 2020); one article was published after our query, and two additional articles were found with a specific google search for “arthroscopy VR Tetris game.” The article describing a game for arthroscopy, included in our primary search, refers to it as the “arthroscopy VR Tetris game.” A specific search on Google for this term and VirtaMed, the operating platform, revealed that this game appears to be part of the ArthroS FAST simulator. A search on PubMed for “ArthroS FAST” and “arthroscopy” produced one article, which, in turn, cited another relevant article about this simulator. However, it was described as a simulator and not as a game, and therefore, was not found in the primary search. Finally, three articles were only found with a specific google search based on two conference abstracts related to the primary search. Full text was not published but could be found on the internet separately. Our strategy described above identified 17 articles to be included in this review.

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Figure 1. Flow chart of study inclusion. KTS: Kheiron training system.



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Textbox 1. Inclusion and exclusion criteria.

Inclusion criteria

- The game was designed to teach a medical intervention usually performed by health care personnel.
- The game was designed to teach a technical skill.
- The technical skill was performed by the player and simulated the real-life technical skill.
- The game was described as a serious game in at least one article.
- The article was available in full text and in the English language.

Exclusion criteria

- The game was designed as a therapy for patients or to teach anything other than a medical intervention.
- The game was designed to teach nontechnical skills (not involving hands-on activity), for example, only knowledge, cognitive skills, and attitudes.
- The technical skills used in the game do not resemble real-life technical skills (training of cognitive skills).
- The approach was described solely as a simulator or other medium (eg, courses, online modules, and mannequin).
- The conference abstract or article was available in a non-English language.

Validity Types for Assessment of Games

Validity in game design for technical skills means that playing the game will actually improve the specific skill in real life. There are several frameworks used for assessment of game validity. The classical framework consists of five different types of validity, and more integrative models are exploring different sources of validity [7]. However, as most reported studies on game validity for technical skills use the classical framework, we have chosen to use that framework for this review. This classical framework consists of the following five different phases of validity: content validity, face validity, construct validity, concurrent validity, and predictive validity [4,5]. Content validity concerns the content of the game to be legitimate (eg, its specifications: Is the game complete and correct, and has nothing but the intended construct [no additional content other than what it was designed for]?). Face validity means that the game appears to be similar to the construct it attempts to represent and is essentially the concept of the game (Do educators or trainees view it as a valid way of instruction?). Construct validity means the game actually measures (or trains) what it intends to measure (Is the game able to measure different skills?). It can be determined by testing prototypes and comparing scores of experts in real life to those of novices. The last stage integrates the construction phase with performance in real life. Concurrent validity reflects the correlation between the performance in the serious game and the performance with the actual instrument. Predictive validity relates the performance in the game to outcomes in reality or predicts skills in real life. In theory, this may require a randomized controlled trial. If the type of validity was not explicitly mentioned, we interpreted the experiment that was conducted and scored the applicable validity.

Results

Search Strategy

The abovementioned search strategy resulted in 17 articles describing five different serious games to train technical skills in health care. We will discuss these five games and their current validity state.

Underground Game

The “Underground” game is the most extensively studied and described. A total of nine articles discussed this Nintendo Wii-U–based game for training basic laparoscopic skills [8-16]. The game was released in 2015 and uses two Wii remote controllers in a custom-made laparoscopic tool shell. The aim is to save robots in a fictional mining world by demolishing and rebuilding the environment. The learning objectives include learning inverted movements, eye-hand coordination, depth perception, and ambidexterity. The face validity, construct validity, and concurrent validity have already been demonstrated and published. It has been shown that playing the game in advance to laparoscopic simulated tasks increased skills [9,16]. Additionally, a study using the game as a preoperative warm-up for 15 minutes showed improvement in task performance [12]. However, the final stage of predictive validity has not been completed yet. This may require comparing surgical skills in the operating theatre between surgeons playing and those not playing the game before the surgery. Several participant characteristics were assessed during these studies. Men outperformed women, and prior video game experience was correlated with “Underground” game scores, although independence of these two variables could not be established as women had less video game experience [10].

Arthroscopic VR Tetris Game

The setup integrates the well-known game “Tetris” into a virtual reality platform for arthroscopic training. The platform consists of a dome with several entry portals for the camera and graspers, and a video screen. The participant can manipulate the Tetris blocks to the preferred position before putting them down. As in the real Tetris game, a line is cleared if it is completely filled with blocks. The aim is to clear 10 lines. The learning objective in this game is to train motor skills, such as opening and closing of graspers and eye-hand coordination. A construct validity study used this setup but with a different assignment, consisting of three activities, and compared the following three groups of users: postgraduate students, fellows, and faculty [17]. Strikingly, the combined scores of the three activities did correlate with year of training but not with prior total

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arthroscopies performed. It would be expected that a higher year of training relates to a higher number of arthroscopies performed and therefore higher scores. Unfortunately, an explanation of this finding was not provided. It is possible that these associations were not significant because the sample size was small or because the game design itself was unable to discriminate the three groups. It is important to emphasize that two validation studies used the arthroscopic simulator setup but not the serious game Tetris. This means that the serious game itself was not validated and that the setup was in fact an arthroscopy simulator. One study with the Tetris game showed that residents performed better with their dominant hand, but this difference disappeared in experienced surgeons [18]. Unfortunately, scores between residents and surgeons were not compared. Interestingly, the second study using the arthroscopic setup showed a gender difference in performance unrelated to previous experience [19].

Kheiron Training System

The Kheiron training system is a serious game for minimally invasive surgery training. The setup includes a box trainer with a box and a camera inside it, real laparoscopic instruments (in contrast to the game "Underwater" that uses the Wii console), a computer, and a monitor. The game is about a young alchemist who has to find the Philosopher's stone by completing different recipes. Two articles provided technical details of the setup and machine learning, but without any kind of validation of the game itself. Only one additional article described the start of the content validity of this game [20]. Other validation studies were announced but have not been published yet.

Relive Game

The setup of Relive consists of a motion detection device (Kinect version 1; Microsoft Corp), a Resusci Anne mannequin, and a laptop. The game is staged on the planet Mars where chest compressions have to be performed on a person with real-time feedback. It can be played in tournament mode. The game was evaluated by a small study with 65 students who played the game at three different time intervals [21]. After a few months, chest compression depths were better than at baseline. However, there was no comparison with students who did not play the game, and no validation was performed in terms of concurrent and predictive validity.

Orthopedic Blood Management Game

This game consists of a computer, a screen, and a haptic device to manipulate surgical instruments and has been developed to train eye-hand coordination by manipulating instruments to stop bleeding on surfaces and in a virtual patient. The game was tested with students, and a subsequent questionnaire indicated that they found the game realistic and helpful, which is the first step in determining content and face validity [22]. Other validation studies have not been published.

An overview of the included articles, the games they discuss, and the validity types is provided in Table 1 [8-24].

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Table 1. Articles included in the review.

Authors	Article title	Game	Validity
Jalink et al [8]	Construct and concurrent validity of a Nintendo Wii video game made for training basic laparoscopic skills	Underground	Construct and concurrent validity
IJgosse et al [9]	Saving robots improves laparoscopic performance: transfer of skills from a serious game to a virtual reality simulator	Underground	Concurrent validity
IJgosse et al [10]	Construct validity of a serious game for laparoscopic skills training: validation study	Underground	Construct validity
Goris et al [11]	Training basic laparoscopic skills using a custom-made video game	Underground	Concurrent validity
Jalink et al [12]	The effect of a preoperative warm-up with a custom-made Nintendo video game on the performance of laparoscopic surgeons	Underground	Concurrent validity
Jalink et al [13]	Face validity of a Wii U video game for training basic laparoscopic skills	Underground	Face validity
Rosser Jr et al [14]	Impact of Super Monkey Ball and Underground video games on basic and advanced laparoscopic skill training	Underground	Concurrent validity
Overtoom et al [15]	Training in basic laparoscopic surgical skills: residents' opinion of the new Nintendo Wii-U laparoscopic simulator	Underground	Construct and face validity
Harrington et al [16]	Playing to your skills: a randomised controlled trial evaluating a dedicated video game for minimally invasive surgery	Underground	Construct and concurrent validity
Tofte et al [17]	Knee, shoulder, and fundamentals of arthroscopic surgery training: validation of a virtual arthroscopy simulator	Arthroscopic VR (Tetris) game	Construct validity
Pedowitz et al [18]	Asymmetry in dominant/non-dominant hand performance differentiates novices from experts on an arthroscopy virtual reality serious game	Arthroscopic VR (Tetris) game	Construct validity
Walbron et al [19]	Evaluation of arthroscopic skills with a virtual reality simulator in first-year orthopaedic residents	Arthroscopic VR (Tetris) game	Construct validity
Sanchez Peralta et al [20]	E-learning serious game for surgical skills training: Kheiron training system	Kheiron Training System	Content validity
Sanchez Peralta et al [23]	Serious game for psychomotor skills training in minimally invasive surgery: Kheiron Training System	Kheiron Training System	Only technical description of the setup, no validation of the game
Martin Vicario et al [24]	Automatic detection of surgical instruments' state in laparoscopic video images using neural networks	Kheiron Training System	Only description of machine learning of the instrument state, no validation of the game
Semeraro et al [21]	Kids (learn how to) save lives in the school with the serious game Relive	Relive	Construct validity
Qin et al [22]	Learning blood management in orthopedic surgery through gameplay	Orthopedic blood management	Content and face validity

Discussion

Principal Results

This review provides an overview of the currently used serious games for improving technical skills in health care and the subsequent validation process. We reviewed 17 articles describing five serious games available for improving technical skills. The game "Underground" has been the most extensively validated, including content, face, construct, and concurrent validity. Most other games only had a description of the initial steps in the process of validation. This means that we are not sure if playing the game will lead to better performance of that specific skill in clinical practice. Most serious games for technical skills need additional validation studies. Guidelines on how to perform validation for serious games may assist game designers and educational experts to develop these games. It is necessary for serious games to be well constructed and evaluated and to impact trainees' performance in real life, especially if expensive software or equipment is needed to play the game.

Frameworks for Validation

Validation of serious games is the process of collecting and interpreting validity evidence, which, in this case, is used to evaluate the appropriateness of a game for improving technical skills in real life [25]. The classical validation framework identified at least three different "types" of validity (content, construct, and criterion). Criterion validity includes correlational,

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concurrent, and predictive validity and denotes the correlation between actual test scores and the "true" (criterion) scores, for example, the correlation with a gold standard. The specifically designed framework for serious games, suggested by Graafland and Warmelink, also uses content and construct validity but adds concurrent and predictive validity instead of criterion validity [4,5]. A more contemporary framework was proposed in 1989 and finally adopted as standard in this field in 1999 and 2014 [26]. Many elements of the classical validation framework are recognizable in this framework, including the construction of the game and its effect on task performance in real practice. It consists of the following five sources of evidence: content, internal structure, relationship with other variables, response process, and consequences [14,15]. Finally, the most recent validation framework was proposed by Kane [27]. The model of Kane is based on inferences and consists of scoring, generalization, extrapolation, and implication. If we apply this framework to serious games, it would start with a player who has a specific score (performance of technical skills) in the game. We assume that the score reflects the overall level of performance, but this score is very dependent on the scoring system/game itself. Multiple scores (or game levels) are combined to generate a total score, assuming this better reflects the performance (technical skills in our case) across the whole test domain (internal consistency). The generalization of the score still deals with performance in the test world and reflects how well the selected test items (scores) represent all of the theoretically possible items. Next, this test world performance is extrapolated to the real world, assuming that this test performance also reflects the skills in real life. Evidence to support extrapolation can be collected by comparing test results with a conceptually related real-world assessment. The final stage is the impact/consequence of this assessment (eg, performance in the game) on the real world (eg, clinical performance, patient safety, length of training, and pass/fail standard). Important questions are as follows: Will playing the game improve or predict technical skills in real life and what are the potential consequences for the trainee?

Although different frameworks for serious games may be used, the validation has the following two key elements: evidence must be collected about the construct of the game itself and its effects on performance in real life. The type of evidence may vary across different games and stages of validation.

Serious Game, Gamification, and Simulation

There is considerable overlap between a serious game, gamification, and a simulator. A serious game is an interactive computer application, with or without specific hardware, that has a challenging goal, is engaging, incorporates some scoring system, and increases the skills, knowledge, or attitudes of its user [3]. These games are designed for specific objectives and therefore differ from commercial video games. A serious game differs from a simulator or gamification in that it uses another context than the actual performance in real life. The game "Underground" is an example of a serious game. In this game, no surgical task is performed or simulated, but the goal is to improve surgical skills. In gamification, there is addition of a game or gaming elements to a nongame context. The game "Relive" is an example of gamification. It uses a normal mannequin to train chest compression but with a scoring element, and the mannequin is "lying on Mars." A simulator is a device that enables the operator to reproduce or represent under test conditions those phenomena that are likely to occur in actual performance. In health care, simulators can be high fidelity, which means they have a high resemblance to the actual context, for example, a fully equipped operating theatre with a mannequin as a patient instead of a real patient. In this review, the "Arthroscopic VR Tetris game" is actually a simulator with realistic instruments, but instead of a virtual patient, it uses the game Tetris, although the same setup is also used for more realistic simulations.

We have attempted to identify factors that influence performance within a game. Unfortunately, the results were inconsistent and differed between games and simulators. It seems that previous gaming experience is at least an independent predictor of game performance. It is unknown if there is also gender inequality. These are interesting topics for future research.

The idea for this review originated from our interest in multiple learning modalities for learning ultrasound skills. However, there are no specific serious games for learning ultrasound skills available at this moment. It is noteworthy that one article describes a serious game for ultrasound-guided needle placement [28]. Although the authors use an interesting setup for learning needle placement, we excluded this article from our review, because in our opinion, it is an ultrasound simulation setup with some gaming elements (gamification) but not a serious game.

Limitations

The literature selection process was primarily done by one reviewer, which may have caused selection bias. However, we used stringent criteria formulated in advance of our search and we received assistance from our experienced librarian. Additionally, the first author cross-checked PubMed for missed publications, although an extensive second search was not performed. Nevertheless, we are confident that no relevant publications have been missed. The search strategy included the word "skill" to eliminate serious games concerning cognitive skills. However, relevant articles describing serious games for technical skills using different words for skills may have been missed, although in the references, we did not find any relevant articles without the word "skill." Moreover, an additional search on PubMed with "psychomotor skills" or "psychomotor performance" did not result in additional articles. It is possible that serious games are being used for teaching technical skills but without any publication in the medical literature. We were not able to address the specific quality of each study as there are no specific quality criteria for validation studies of serious games. We excluded four non-English articles and 10 conference abstracts. We translated and reviewed them, but they were not of additional value. Thus, the exclusion did not cause relevant selection bias.

Conclusions

To date, only a few serious games exist for the training of technical skills in medical education, and serious games for learning ultrasound skills are lacking. Factors predicting performance in serious games are only briefly known. The

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majority of games still need full validation. This is especially true if they require expensive software and/or hardware. Serious games can be evaluated with the classical concept of validation consisting of content validity, face validity, construct validity, concurrent validity, and predictive validity, although more integrative frameworks are advocated. This review may help serious game developers in the validation process of their games. Despite the specific process of validation, the ultimate goal of serious games is to improve technical skills in real life in a fun way.

Conflicts of Interest

None declared.

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Original Paper

A Web-Based Game for Young Adolescents to Improve Parental Communication and Prevent Unintended Pregnancy and Sexually Transmitted Infections (The Secret of Seven Stones): Development and Feasibility Study

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Abstract

Background: Early adolescent unintended pregnancy and sexually transmitted infection prevention are significant public health challenges in the United States. Parental influence can help adolescents make responsible and informed sexual health decisions toward delayed sexual debut; yet parents often feel ill equipped to communicate about sex-related topics. Intergenerational games offer a potential strategy to provide life skills training to young adolescents (aged 11-14 years) while engaging them and their parents in communication about sexual health.

Objective: This study aims to describe the development of a web-based online sexual health intergenerational adventure game, the *Secret of Seven Stones* (SSS), using an intervention mapping (IM) approach for developing theory- and evidence-based interventions.

Methods: We followed the IM development steps to describe a theoretical and empirical model for young adolescent sexual health behavior, define target behaviors and change objectives, identify theory-based methods and practical applications to inform design and function, develop and test a prototype of 2 game levels to assess feasibility before developing the complete 18-level game, draft an implementation plan that includes a commercial dissemination strategy, and draft an evaluation plan including a study design for a randomized controlled trial efficacy trial of SSS.

Results: SSS comprised an adventure game for young adolescent skills training delivered via a desktop computer, a text-based notification system to provide progress updates for parents and cues to initiate dialogue with their 11- to 14-year-old child, and a website for parent skills training and progress monitoring. Formative prototype testing demonstrated feasibility for in-home use and positive usability ratings.

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Conclusions: The SSS intergenerational game provides a unique addition to the limited cadre of home-based programs that facilitate parent involvement in influencing young adolescent behaviors and reducing adolescent sexual risk taking. The IM framework provided a logical and thorough approach to development and testing, attentive to the need for theoretical and empirical foundations in serious games for health.

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KEYWORDS

serious game; intervention mapping; sexual health; adolescents; sexually transmitted infections; teenage pregnancy; parent, communication; intergenerational; mobile phone

Introduction

Background

Early sexual debut in adolescents is a pervasive public health challenge in the United States. Nearly half (46.8%) of high school students reported having engaged in sexual intercourse, whereas 5.6% reported having engaged in sex before the age of 13 years [1]. Furthermore, teenagers and young adults (aged 10-24 years) represent approximately 90% of single parents and half of all new cases of sexually transmitted infections (STIs) [2,3]. Sexuality and gender identity typically emerge during early adolescence around 10 to 14 years of age, a period corresponding with early experimentation with sexual behaviors [4]. However, it is also a time of receptivity to health messages and therefore opportune for interventions to positively influence future sexual health decision making [4].

School- and clinic-based prevention programs often achieve broad support and success in reducing sexual risk behaviors in young adolescents [5-14]. Conversely, these programs often face implementation barriers such as perceptions of sex education as controversial, limited time and resources, and lack of fidelity [14-17]. Furthermore, school- and clinic-based programs face challenges in effectively involving parents as an unintended pregnancy and STI and HIV prevention mediator. A growing body of research supports the importance of parents' influence on young adolescent risk behaviors; however, many parents express reluctance to discuss sex with young adolescents because of the belief that they lack time, knowledge, or appropriate skills [18-20]. Young adolescents also report a desire to discuss sexual health–related topics with their parents but feel that their parents need training on how to communicate about these topics [21]. Web-based and mobile technology may provide utility in reaching young adolescents and parents with novel sexual health skills training programs [22-24]. Serious gaming offers promise as an innovative and efficacious approach to sexual health education, operating as a forum to promote a common intergenerational experience, and as a catalyst for increased communication [25-36]. Recent research on parent-based adolescent sexual health education suggests promise for the use of intergenerational games in enabling collaborative engagement across age groups [37].

Purpose

The purpose of this study is to describe the development of a novel in-home web-based intergenerational game for parent and young adolescent (11-14 years) dyads, the *Secret of the Seven Stones (SSS)*, designed to provide sexual health skills training to young adolescents and to positively impact dyadic sexual health communication. SSS is played on internet-accessible devices through the Adobe Air framework and comprises 18 game levels (each of 45 min of game play) with 50 interactive skills training clusters, 54 card *battle* sequences, and 7 game-mediated parent-young adolescent partner-engage-plan (PEP) talks. Players adopt an avatar to negotiate the town of Seven Stones and assume a hero's quest to liberate the inhabitants when their personal life rules are challenged in contexts of maintaining healthy friendships, understanding puberty and reproduction, having healthy dating relationships, refusing sex, and negotiating safe sexual practices. The player must *power-up* their wisdom, skill, and support capabilities in these domains (represented in the game as battle cards) in a dojo using skill training and rehearsal mini-games, animations, puzzles, quizzes, role modeling, and peer video. The player can then liberate an inhabitant by winning a card *battle*, releasing them from misperceptions, poor judgment, and bad decision making. At 7 milestones in the game, the player is cued to have a PEP talk with their collaborating parent who is a gatekeeper, conferring a code that enables continuation of the quest. PEP talks focus on the concepts and strategies covered in the game and also introduces each of the 7 character traits that are important in navigating one's life decisions (eg, respect, vision, persistence, caring, responsibility, courage, and integrity). Throughout the game, SMS text prompts notify the parent of the player's progress, cue them to an upcoming PEP talk, and link them to parent website resources that can assist with the PEP talk, providing progress tracking, supporting videos, and downloadable fact sheets. Theoretical methods and practical applications guide behavioral skills training that draws from 135 performance behaviors and over 1300 learning objectives within 15 sexual health domains encompassing responsible decision making about communication, friendships, dating relationships, sex, and social support. SSS was developed using the intervention mapping (IM) framework [38]. The development process is described in the context of each of the six IM steps.

Methods

Overview

We developed SSS through a National Institutes of Health (NIH) Small Business Technology Transfer Research (STTR) project collaborative between UTHealth (The University of Texas Health Science Center Houston) and Radiant Creative Group, LLC. Our development team comprised specialists in adolescent sexual health, computer-based interventions, parent-child

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communication, and digital media development. The Parent-Youth Advisory Group (P-YAG) provided conceptual guidance and formative evaluation. Parents (n=20) and young adolescents (n=19, aged 11-14 years) were recruited through flyers, targeted Facebook advertisements, and word of mouth. Young adolescents were mainly female (13/19, 68%), mean 12 (SD 0.28) years old, African American (9/19, 47%), and White (8/19, 42%). Parents were mainly mothers (17/20, 85%), African American (8/20, 40%), White (9/20, 45%), and Hispanic (3/20, 15%). IM, a 6-step framework for developing evidence- and theory-based intervention programs, guided our development process (Table 1) [38]. Our study was approved by the University of Texas UTHealth Institutional Review Board. At the initial P-YAG meeting, parents and young adolescents signed consent and assent forms, respectively.

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Table 1. Intervention mapping steps with associated tasks and intermediate development products.

IM[a] steps	IM tasks	Intermediate development products[b]
Step 1: Assess need & develop a logic model of the problem	• Establish and work with a planning group. • Describe the context for the intervention, including the population, setting, and community. • Conduct a needs assessment to create a logic model of the problem.	• P-YAG[c] • Literature review–evidence table • PRECEDE[d] model
Step 2: Develop matrices of change objectives	• State expected outcomes for behavior and environment. • Specify performance objectives for behavioral and environmental outcomes. • Select determinants for behavioral and environmental outcomes. • Construct matrices of change objectives.	• Matrices for parent (n=6), youth (n=8), and dyadic (n=1) outcome behaviors comprising performance objectives for parent (n=65), youth (n=70), and dyad (n=8) and learning objectives for parent (n=869), youth (n=781), and dyad (n=72). • Conceptual model for SSS[e] game flow (model of change).
Step 3: Identify theory-based methods and practical applications for program design	• Choose theory- and evidence-based methods to create change. • Select or design practical applications to deliver change methods. • Generate program themes, channels, components, scope, and sequence.	• Table of content domains (n=9). • SSS design document comprising specifications including functional inventory, game flow, screen map design, game mechanics, scripts, character descriptions, and interactive activities.

Step 4: Produce program components and materials	• Refine program structure and organization.
	• Prepare plans for program materials.
	• Draft messages, materials, and protocols.
	• Pretest, refine, and produce materials.
		• SSS game consisting of 18 levels of content.
		• SSS parent website including parent training videos (n=7) and tip sheets (n=10).
		• Pilot test protocols and results:
		  • Manual of procedures.
		  • Usability rating results table (parent & youth) with ratings on ease of use, acceptability, credibility, motivational appeal, and applicability for 2 prototype levels.
		• Qualitative data (parent and youth) on acceptability for in-home use.

Step 5: Plan for program adoption, implementation, and sustainability	• Identify potential program implementers. • State outcomes and performance objectives for implementation. • Construct matrices of change objectives for implementation. • Design implementation interventions.	• Marketing and commercialization plan for future implementers. • Written University of Texas Tech Transfer agreement. • SSS game and website revisions for future implementation.

Step 6: Plan for evaluation	• Write effect and process evaluation questions.
	• Develop indicators and measures for assessment.
	• Specify evaluation design.
		• Efficacy study design Manual of Procedures comprising:
		  • Study hypotheses and protocols.
		  • Baseline and first and second follow-up Questionnaire Development System (QDS) software and paper-based surveys.
		  • Qualitative exit interview prompts.

[a]IM: intervention mapping.

[b]Youth indicates young adolescents (11-14 years).

[c]P-YAG: Parent-Youth Advisory Group.

[d]PRECEDE: predisposing, reinforcing, and enabling constructs in educational diagnosis and evaluation.

[e]SSS: Secret of Seven Stones.

Intervention Development

IM is a stepped framework to guide the development of behavioral interventions, providing a process by which program developers can apply social and behavioral science theories within the practice of health behavior change [38]. It comprises 6 primary steps: (1) assess needs and develop a logic model of the health problem; (2) develop matrices of behavioral change objectives; (3) identify theory-based methods and practical applications to design the program; (4) produce program components and materials; (5) plan for program adoption, implementation, and sustainability; and (6) plan for evaluation [38]. IM is widely used to design disease prevention and disease management interventions worldwide. A recent systematic

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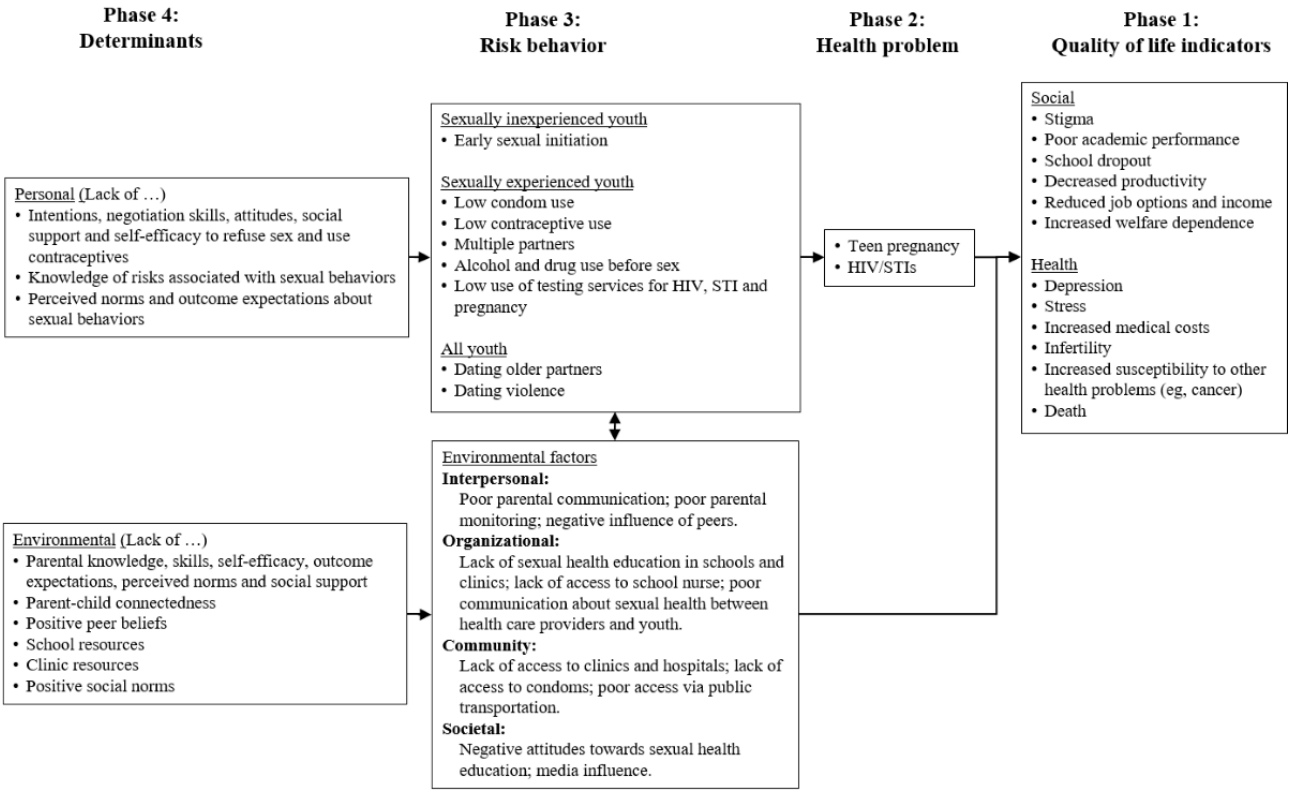
review has demonstrated a significant increase in the uptake of disease prevention behaviors associated with IM-based interventions and placebo control groups [39]. IM has been successfully applied in the domain of sexual health, including interventions to promote increased communication between parents and young adolescents on relationships and sex [39,40]. However, few applications of IM have been reported in the context of serious games for health, and to our knowledge, none in the context of intergenerational video games for health [41,42].

Results

Step 1: Assess Need and Develop a Logic Model of the Problem

In step 1, we conducted a needs assessment to understand the health problem and priority population and to describe a theoretically- and empirically-based model for sexual health behavior (Table 1) [38]. PRECEDE (predisposing, reinforcing, and enabling constructs in educational diagnosis and evaluation) provided a framework for developing a logic model of the problem [38]. The model prescribes an *analysis of causation* for a health promotion problem that accounts for multiple ecological levels as well as the multiple determinants of a health-related behavior and environment. National statistics, data from our previous empirical studies on sexual health, qualitative data from 6 P-YAG focus groups, and a literature review of behavior change theories (principally Social Cognitive Theory, social influence models, and the theory of triadic influence) informed our development of a PRECEDE logic model describing quality of life issues and behavioral, social, and physical influences related to adolescent sexual risk behaviors (Figure 1) [28,43-49]. National statistics indicated that early sexual debut is correlated with increased risk of STIs and unintended pregnancy, increased number of sexual partners, more frequent sex, use of alcohol or drugs before sex, and reduced condom use [50-56]. Possible quality of life consequences includes increased high school dropout, welfare dependence, and negative health outcomes for children of teens [57,58]. Environmental factors include limited parent-child communication about sexual health and parental monitoring (Figure 1) [59,60].

Figure 1. Predisposing, reinforcing, and enabling constructs in educational diagnosis and evaluation "logic model of the problem" of young adolescent sexual behavior for the Secret of Seven Stones. STI: sexually transmitted infections.



Our needs assessment determined a priority population of young adolescents (aged 11-14 years) and their parents and program goals to increase young adolescent intentions to delay initiation sex until they are older and increase parent-child sexual health communication to delay sexual initiation. P-YAG recommendations for sexual health topics included puberty, sexual behavior, and STIs and skill building on parent-young adolescent communication, negotiation, and decision making [46]. Parents wanted to be a credible and focal resource in their child's sexual health education, and both parents and young adolescents wanted to be more comfortable and effective in initiating and maintaining the conversation around sexual health [46]. Our needs assessment confirmed that parents and young adolescents enjoyed playing a variety of digital games, often on smartphones, and acknowledged the bonding experience of games which, when played together, were played most frequently at home [46].

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Step 2: Develop Matrices of Change Objectives

In step 2, we described the behavioral outcomes, delineated these behaviors into their component parts (performance objectives), specified behavioral determinants, and developed change (learning) objectives (Table 1).

Behavioral Outcomes

Drawing from our needs assessment findings and our previous studies, we identified 15 outcome behaviors that were important for the current program (Table 2) [30,31,46,61]. Outcome behaviors for young adolescents comprised delayed initiation, condom use, contraceptive use, human papillomavirus (HPV) vaccination, healthy peer and dating relationships, HIV and STI testing, parental monitoring, and young adolescent to parent communication. Decision making for sexual risk reduction can follow a self-regulation framework of s*elf-monitoring* to determine if behaviors are in accordance with one's values and consistent with one's goals, s*elf-judgment* to identify the presence of threats to these values, such as risky situations, s*elf-reaction* to take appropriate action (eg, avoidance or using refusal skills), and *self-evaluation* to assess the success of the chosen action [62]. Young adolescents have demonstrated capability in engaging in self-regulation that can provide a cognitive framework for navigating life challenges and reducing health risks [63-65]. Furthermore, young adolescents have demonstrated achievement in processing extensive sexual health curricula content and effectively translating this into behavioral outcomes [28,29,31]. Outcome behaviors for parents comprised parental monitoring; general parent to young adolescent communication; and parent communication about condom use, contraceptive use, HIV and STI testing, and HPV vaccination. The outcome behavior at the level of the dyad (parent and young adolescent) was dyadic communication.

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Table 2. Outcome behaviors for young adolescents, parent, and dyad with performance objectives for the dyadic (parent-young adolescent) communication outcome behavior.

Learner–domain	Outcome behavior
Youth[a]	
Healthy peer and dating relationships	Youth will have healthy peer and dating relationships
Abstinence	Youth will not have sex
Condom use	Youth who are sexually active or considering having sex will use condoms correctly and consistently when having sex
Contraceptive use	Youth who are sexually active will use effective method of birth control along with condoms
HIV and STD[b] Testing	Youth who are sexually active will get tested and counseled for HIV and STD and unintended pregnancy
HPV[c] vaccination	Youth will complete the 3-dose HPV vaccination series
Parental monitoring	Youth will establish common rules with parents about supervision and monitoring
Youth to parent communication	Youth will communicate with their parents about dating, intimate or healthy relationships, and sexual behaviors
Parent	
Parental monitoring	Parents will monitor their youth's adherence to personal rules
Parent to youth communication	Parents will communicate with their youth about dating, healthy intimate relationships, and sexual behaviors
Condom use	Parents will talk to their youth about condom use when having sex
Contraceptive use	Parents will talk to their youth about contraceptive methods
HIV and STD testing	Parents will talk to their youth about getting tested and counseled for HIV and STD and unintended pregnancy
HPV vaccination	Parents will talk to their youth about completing the 3-dose HPV vaccination series
Dyad	
Dyadic communication	Parents and youth will interact in a mutually engaging and responsive communication process to achieve shared goals
Performance objectives for dyadic communication	• PO[d].1: Parent and youth will pick the right time and place (T&P) to talk. • PO.2: Parent and youth will converse with respect. • PO.3: Parent and youth will assess the youth's motivation to engage in the behavior under discussion. • PO.4: Parent and youth will assess alternative actions to the behavior under discussion and their benefits and consequences. • PO.5: Parent will share their values and expectations regarding possible behaviors (the behavior under discussion and alternate actions). • PO.6: Parent and youth will develop the best plan of action together. • PO.7: Parent and youth will encourage each other to keep communicating openly. • PO.8: Parent and youth will reflect on what to do the same or differently next time.

[a]Youth refers to young adolescent (11-14 years).

[b]STD: sexually transmitted disease.

[c]HPV: human papillomavirus.

[d]PO: performance objective.

Performance Objectives

We identified 143 performance objectives (sub-behaviors) that are necessary to complete the outcome behaviors. Table 2 shows the performance objectives for dyadic communication.

Behavioral Determinants of Sexual Behavior

Once the target behaviors were defined, we used theory and empirical applications of theory, including our literature review and previous studies to guide the identification of determinants that likely influence successful performance. Determinants that have been described as impacting sexual behavior in young adolescents include constructs derived from the Social Cognitive Theory, social influence models, and the theory of triadic influence [28-31,47-49,61]. Programs grounded in these theories demonstrated success [28,29,31,44,45]. The determinants included behavioral capability (declarative and procedural knowledge of risk reduction and communication behaviors),

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skills and self-efficacy (capability and confidence to perform risk reduction and communication behaviors), outcome expectations (belief that risk reduction behaviors and communication will lead to important results), perceived norms (belief that significant others believe in and use risk reduction behaviors), and social support (recognition of social others who can assist in risk reduction; Figure 1) [59,60].

Behavioral Determinants of Game Play

We also attended to determinants of game play using motivational theory to optimize learner attention [66-71]. Hypothesized determinants included challenge (defined and personally meaningful goals and uncertain, difficult, and yet attainable game outcomes that are predicated on personal effort), curiosity (through novel and surprising game environments, including novel sensory stimuli, and results that can only be confirmed through play), control (through game environments and consequences that are subject to learner action), and self-efficacy (through successive positive reinforcement provided through play).

Matrices of Change Objectives

We defined the program learning objectives by creating separate matrices of performance objectives (row headings) and determinants (column headings) for each outcome behavior. Table 3 provides an example of a partial matrix for dyadic communication behavior (from the example in Table 2). In each matrix cell, we described the learning objective, related to a particular determinant, which contributes to achieving the performance objective. For example, in Table 3, the dyad needs to demonstrate the capability (skill determinant S1.1) to pick the right time and place to converse (performance objective). For interested readers, matrices are available from the corresponding author.

Table 3. Parent matrix for the dyadic parent-youth communication outcome objective that parents and children will interact in a mutually engaging and responsive communication process to achieve shared goals.

PO[a]	Determinants of behavior						
	Knowledge	Skills	Self-efficacy	Outcome expectations	Perceived norm	Perceived barriers	Social support
PO.1 Parents and child will pick the right T&P[b] to talk	• K1.1. State that the right T&P is one where both parent and child are focused and calm. • K1.2. Describe the influence of emotions, preconceived thoughts, and distractions on communication. • K1.3. State the importance of being aware of these influences and setting them aside before initiating communication.	• S1.1. Demonstrate the ability to pick the right time and place to converse. • S1.2. Demonstrate the ability to set aside emotional or cognitive predispositions before conversing.	• SE1.1. Demonstrate the confidence to pick the right time and place to converse. • SE1.2. Demonstrate the confidence in ability to set aside emotional or cognitive predispositions before conversing.	• OE1.1. State that picking the right T&P will lead to a more focused and calm discussion. • OE1.2. State that reflecting on one's emotions, preconceived thoughts, and distractions before communication will facilitate open and respectful communication.	• PN1.1 State that other parents and children have greatest communication success when they pick the right T&P.	• PB1.1. State ways to overcome barriers to selecting a right T&P to communicate (schedule or environment). • PB1.2. Recognize barriers to being aware of and setting aside one's emotions or cognitions before conversing.	• SS1.1. Identify others who can help in arranging a right T&P to converse.

[a]PO: performance objective.

[b]T&P: time and place.

Step 3: Identify Theory-Based Methods and Practical Applications for Program Design

In step 3, we identified theoretical methods and practical applications to inform program design (Table 1).

Theory-Based Methods

A theoretical method is a general technique that influences the determinants of behaviors. If a young adolescent theoretically requires the knowledge, skills, self-efficacy, positive outcome expectations, positive perceived norms, and engagement of social support to perform sexual risk reduction and communication behaviors, then an effective sexual health

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education program needs to elicit positive change in these determinants. We drew from empirical literature and our previous research on sexual health and web-based curricula [38]. Table 4 provides an example of the dyadic performance objective to pick the right time and place to converse. We derived methods to increase skills and self-efficacy that comprised informing and consciousness raising, goal setting, chunking, verbal persuasion, modeling, enactive mastery, and public commitment (Table 4).

Table 4. Partial (example) matrix of methods and applicationsa.

Method (and theory)	Practical application	
	For youth	For parents
Information and consciousness raising	Communication activity describing PEP[b] steps and importance of respectful communication; SDP[c] activity teaching how to use this tool to protect personal rules; RRR[d] to manage emotions; and "What kind of friend are you" quiz and activity.	PEP Talks 101 and SDP tip sheets with communication tips and "Ask the Expert" advice on communicating about specific topics and information on planning ahead to protect rules; and parent/youth video testimonials illustrating benefits of talking.
Goal setting (theories of self-regulation and Social Cognitive Theory)	Prompt to set personal rules before each PEP Talk and develop strategies with parent.	Personal rule to orient communication and expectation.
Chunking (information processing)	PEP to teach steps of PEP Talk; RRR to manage emotions; and SDP tool to help youth maintain personal rules.	PEP to teach steps of healthy communication and SDP tool to help youth maintain personal rules.
Verbal persuasion (Social Cognitive Theory)	SDP activity training and practice by presenting youth with pressure lines in various situations and asking youth to select appropriate response and RRR activity to manage emotions.	PEP Talk videos; parent and youth video testimonials illustrating how other parents talk to their children and describing how to talk about family values to set rules; Virtues tip sheet reviewing virtues and how to talk about them; and PEP Talk question prompts.
Modeling (Social Cognitive Theory)	Parent and youth video testimonials on communication and discussing values.	Parent and youth video testimonials on communication and discussing values.
Enactive mastery (Social Cognitive Theory)	Communication activity reviewing PEP steps and how to choose right time and place to talk; SDP activity training and practice by presenting youth with pressure lines in various situations and asking youth to select appropriate response; RRR activity to manage emotions; and prompt for youth to enter personal rules and strategies. Content progresses in terms of *maturity*.	PEP Talk videos; Virtues tip sheet reviewing virtues and how to talk about them; and PEP Talk question prompts.
Public commitment (transtheoretical model)	Discussing rules and strategies with parent during PEP Talk and then entering rules into game where they can be viewed by youth and parent throughout the game.	Rules and strategies inform social support

[a]Outcome behavior: Parents and children will interact in a mutually engaging and responsive communication process to achieve shared goals. Performance objective #1: Parents and children will pick the right time and place to talk. Determinant and change objective: Skills (S1.1) and self-efficacy (SE1.1) to pick the right time and place to converse. Youth refers to young adolescent (ages 11-14 years).

[b]PEP: partner-engage-plan.

[c]SDP: select, detect, protect.

[d]RRR: relax, rewind, replay.

Given that we were designing a serious game, we also adopted methods to influence the determinants of young adolescent persistence in game play. To address learner challenge, we designed the game to include goals to accomplish and milestones to reach and provided game scenarios of moderate difficulty [66,67,72-75]. Progress was designed to be reinforced verbally by the dojo master and with performance-based rewards (eg, higher quiz scores provide stronger battle cards and virtue tokens that can assist in winning battles) to impact self-efficacy for game play [47]. To address learner curiosity, we embedded scenarios of real-life challenges in the *fantasized* content of a gaming motif, featuring novel locations and characters [66,68,69]. We appealed to learner sensory curiosity by providing multiple modalities to convey information (sound, graphics, video, and animation), and provided opportunities for learner control with flexibility in the selection of content exposure and battles [71,76-78].

Practical Applications

Practical applications refer to the mode and context of program delivery that fits with the priority population. These comprise channel, scope and sequence, and theme. We designed the program to operationalize the theory-based methods and to be responsive to needs assessment recommendations from the P-YAG [46].

Theme

We provided 2 underlying themes. The first theme was that young adolescents do not have to "go it alone," that the parent is a social support, dyadic communication is important, and that the discomfort and lack of confidence to discuss sexual health

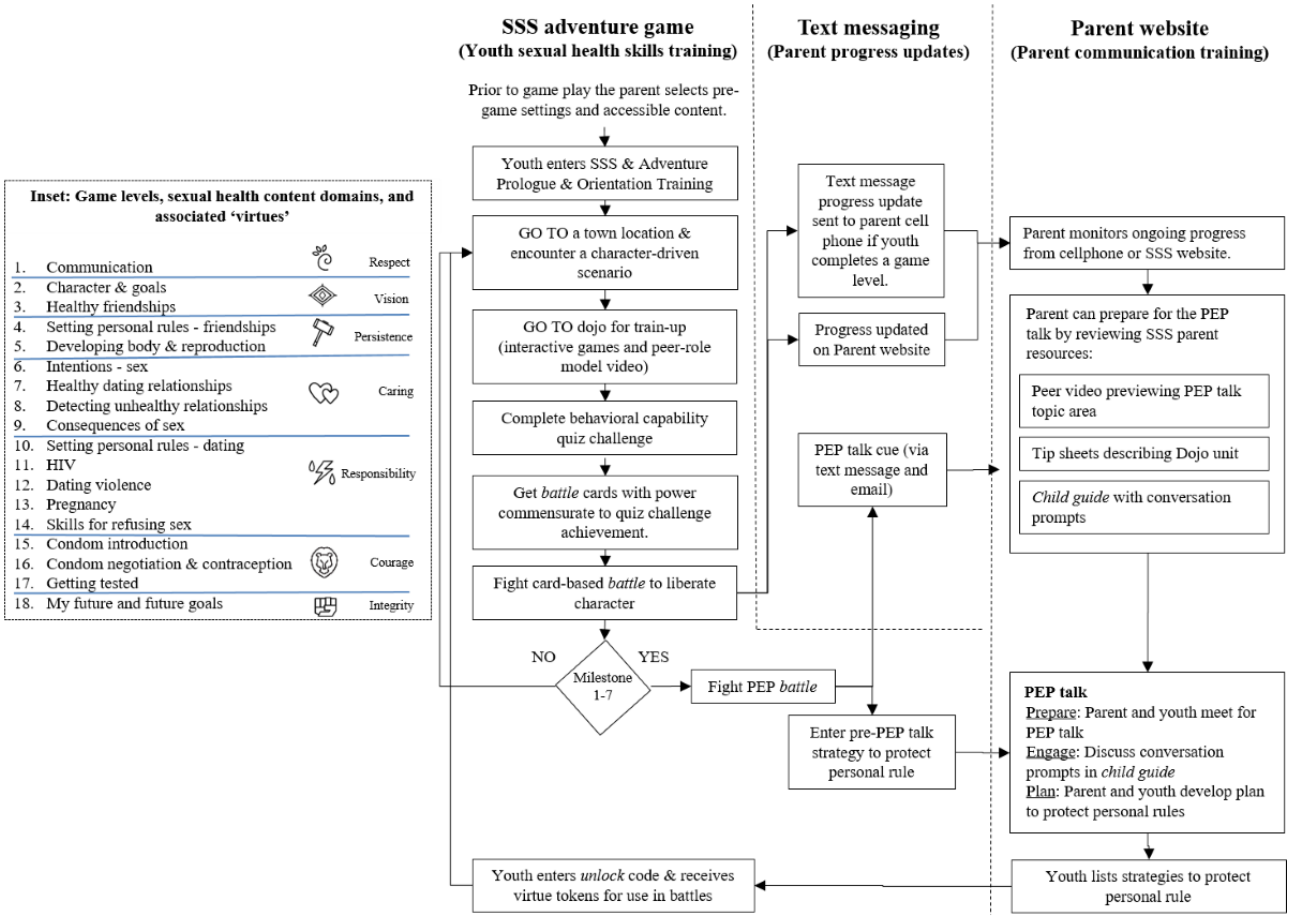
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topics (by both young adolescent and parents) can be overcome with skills to initiate and maintain the sexual health dialogue. The second underlying theme was that young adolescents have control of their life decisions and that smart life decisions (based on self-regulation by selecting, detecting, and protecting their personal rules) have positive consequences. The game motif was a quest to liberate the citizens of the town of Seven Stones from the control of an evil villain, Frostbyte. The young adolescent is victorious if they can defeat Frostbyte in a final *boss* battle.

Channels

SSS comprised (1) an adventure game for young adolescent skills training delivered via a desktop computer, (2) a text-based notification system to provide progress updates for parents and cues to initiate dialogue with their young adolescent, and (3) a website for parent skills training and progress monitoring (Figure 2).

Figure 2. The Secret of Seven Stones program scope and sequence of play and content domains (inset). PEP: partner-engage-plan; SSS: the Secret of Seven Stones.

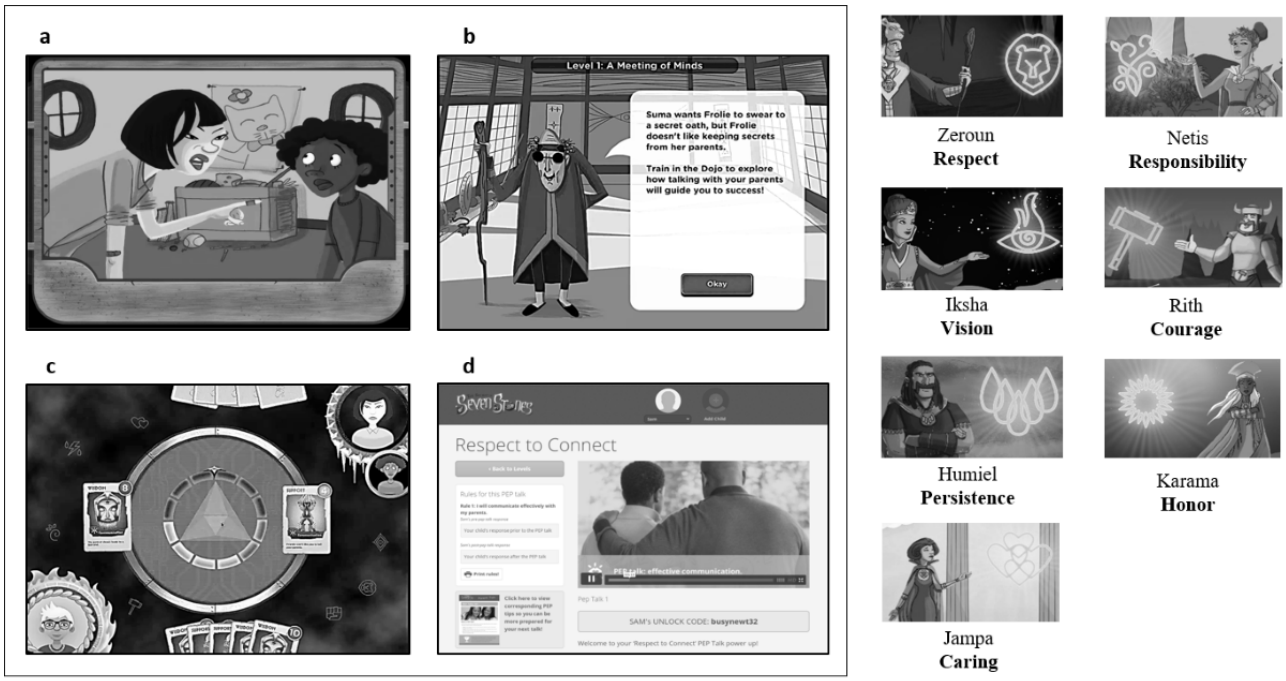


Scope and Sequence

We designed the SSS interactive adventure game to provide sexual health skills training primarily for young adolescents because, although dyads supported a gaming strategy, parent time constraints would not accommodate extensive parental gameplay. As such, we designed SSS to accommodate parents in an adjunct, supporting, and gatekeeper role. The game had 18 levels to accommodate the educational content. Each game level approximated 45 to 60 min of game play and contained multiple short duration (2-5 min) activities. The SSS game sequence required young adolescents to (1) visit a location in Seven Stones and encounter citizens who are facing a sexual health challenge (eg, a conflict between being true to yourself vs maintaining a friendship); (2) enter the *Dojo* to complete educational activities, which were adapted from pre-existing evidence-based curricula and to *power-up* on relevant knowledge and skills; (3) complete a *challenge quiz* to earn battle cards of wisdom, skill, and support; and (4) initiate a card-based *battle* to liberate the citizen *opponent* (Figures 2 and 3). Dojo activities comprised interactive and noninteractive animations, mini games, role model videos, and role-playing activities from our previous curricula [28,30,31,43,61]. These activities used methods of consciousness raising, chunking, goal setting, verbal persuasion, modeling, enactive mastery, and planning coping responses and have been demonstrated to be effective in promoting behavior change in previous studies (Table 4) [28,31,43,79,80].

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Figure 3. The Secret of Seven Stones (SSS) sample game and parent website screens and personified virtues. (a) Animated video introducing "Suma" and "Frollie" and the challenge scenario that requires resolution, (b) the "Dojo" (and Dojo master, Alfred) where the player receives skill training activities to prepare for "battle," (c) card battle with wisdom, skill, and support cards to liberate Frollie, and (d) SSS parent website featuring parent resources (videos and tip sheets) to enable parent competency in partner-engage-plan talks, and an array (on right) of personification and imagery of virtues referred to in the game.



The program title, SSS, derives from (1) the town of Seven Stones, (2) the 7 supportive parental interactions during the quest, and (3) the 7 character virtues acquired at each of these dialogues (Figure 2 inset). SSS was designed to (1) provide a common foundation for talking points drawn from the game experience; (2) train young adolescents (and provide resources to parents) on how to communicate; (3) take a *life skills* approach that introduces character traits, healthy friendships, and rule setting long before discussing sex; and (4) providing the opportunity for ongoing dialogue to *normalize* such discussions, allowing a more subtle transition to sexual health topics over time.

The parent is updated on the young adolescents' progress through text messages (Figure 2). At each of the 7 game *milestones* the young adolescent is *locked out* of the game and the parent is cued (via text message and e-mail) to have a PEP talk with their young adolescent. In a *PEP* talk, parents and young adolescents decide a time and location to have a face-to-face discussion (partner), discuss personal and family rules (engage), and develop goals and strategies to maintain these rules (plan). Upon completion of a PEP talk, the parent provides an *unlock* code, enabling the young adolescent to receive cards and virtue tokens to use in future battles (Figures 2 and 3).

SSS provides increased challenge by sequencing content from topics with less *mature* content early in the game (eg, healthy friendships) to more *mature* content later in the game (eg, sexual risk reduction). Early PEP talks focus on friendships and decision making to *normalize* discussions and make the transition to later discussions of reproduction and sexual relationships less abrupt and awkward. The SSS is designed to accommodate family values. A control feature allows parents to delay the delivery of more *mature* content of condoms and contraceptives to a time when they perceived their young adolescent to be developmentally ready. The SSS parent website recommends that children be exposed to all content and that content is provided sequentially ensuring foundational material is mastered before exposure to more *mature* content.

SSS was designed to respond to game preferences emanating from the focus groups. A general preference for boys was the quest to defeat Frostbyte in a boss battle, with girls to resolve interpersonal relationship conflicts among the citizens of Seven Stones, and both girls and boys to use card games for *battle*. SSS was designed to be responsive to the needs of lesbian, gay, bisexual, transgender, queer, and intersex (LGBTQI) young adolescents with activities that are were inclusive of sexual minority preference (eg, scenarios in which young adolescents can choose a partner of either gender and use gender-neutral names) and with materials (eg, fact sheets) that focus on sexual minority issues (eg, LGBTQI and sexuality defined, self-acceptance, the notion of what *normal* means, social support ["Who can I talk to?"], things to consider before coming out at home, and organization resources).

We designed an SSS website (Figures 2 and 3) to promote communication skills training for both mothers and fathers to enable parents to be a more credible resource in their young adolescents' sexual health education. Resources comprised 15 PEP talk and communication role model videos featuring parents and young adolescents and 10 communication tip sheets. PEP talk videos were of 2-min duration, introduced the content of the PEP Talk, updated on the educational content covered by their young adolescent, and provided tips on preparing for their PEP Talk. Testimonial videos showed both mothers and fathers and young adolescent role models describing their real-world

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interactions and positive communication experiences. Tip sheets provided summaries of game content, strategies for engaging their young adolescents in conversation, and exercises to increase communication skills and self-efficacy.

Step 4: Produce Program Components and Materials

In step 4, we produced and pilot tested an SSS prototype comprising the first 2 game levels (Table 1).

Prototype Development

We designed SSS for installation on desktop computers (both Windows and Mac) using the Adobe Interactive Runtime through a broadband connection. The back end mini Structured Query Language (MSQL) database and parent website were implemented using a web server running Hypertext Preprocessor (PHP) built on the Yii framework and accessible through standard browsers using a broadband connection. The back end database was designed to store game data allowing *pause points* that allow players to exit and re-enter SSS without loss of game progress [46].

Prototype Feasibility Testing

We conducted a 2-week pilot test of feasibility in the homes of 10 dyads to determine functional integrity, acceptability by parents and young adolescents, and to explore psychosocial impact. This sample size is sufficient for usability testing and comprises young adolescents (aged 11-14 years; mean 13.1, SD 1.20 years, predominantly males (7/10, 70%), and of White (5/10, 50%) and Hispanic (3/10, 30%) ethnicity [81,82]. Young adolescents were experienced with games; they reported playing for 5 to 8 hours a week (4/10, 40%), playing first-person shooter and multiplayer games (3/10, 33%), and playing on gaming consoles (6/10, 60%) and cell phones (5/10, 50%). Parents comprised mainly mothers (8/10, 80%) and reported either not having played in the last 3 months (4/10, 40%) or playing for less than 2 hours (3/10, 30%). Most played creative or casual games (10/10, 100% and 8/10, 80%, respectively) and all participants played on their cell phones (10/10, 100%).

Measurement

We collected parent and young adolescent self-report data using computer-assisted self-administered surveys on study laptops at baseline and at the 2-week follow-up. Our pilot study enabled the testing of protocols to be employed in subsequent efficacy testing. Parent consent and young adolescent assent were obtained before data collection. The feasibility process measures comprised system access logs and user reports (written and verbal) of program issues. Dyads rated SSS on likeability, ease of use, duration, understandability, credibility, perceived impact, and motivational appeal using previously described rating scales [30]. They also assessed the commercial potential of the SSS (discussed in step 5 below). An exploratory analysis was conducted on the impact of SSS on psychosocial determinants of parent-young adolescent communication regarding sex (perceived quality of communication, self-efficacy for parent-child communication, outcome expectations for communication, communication ability, communication openness, and parent-young adolescent connectedness) and attitudes toward using digital games for learning (using an adapted 12-item scale) [83-87]. Scales were provided as pretests before SSS use and at the 2-week follow-up. The Wilcoxon signed-rank test was used as a nonparametric alternative to a *t* test as the sample size (n=10 dyads) was too small to assume normal distribution.

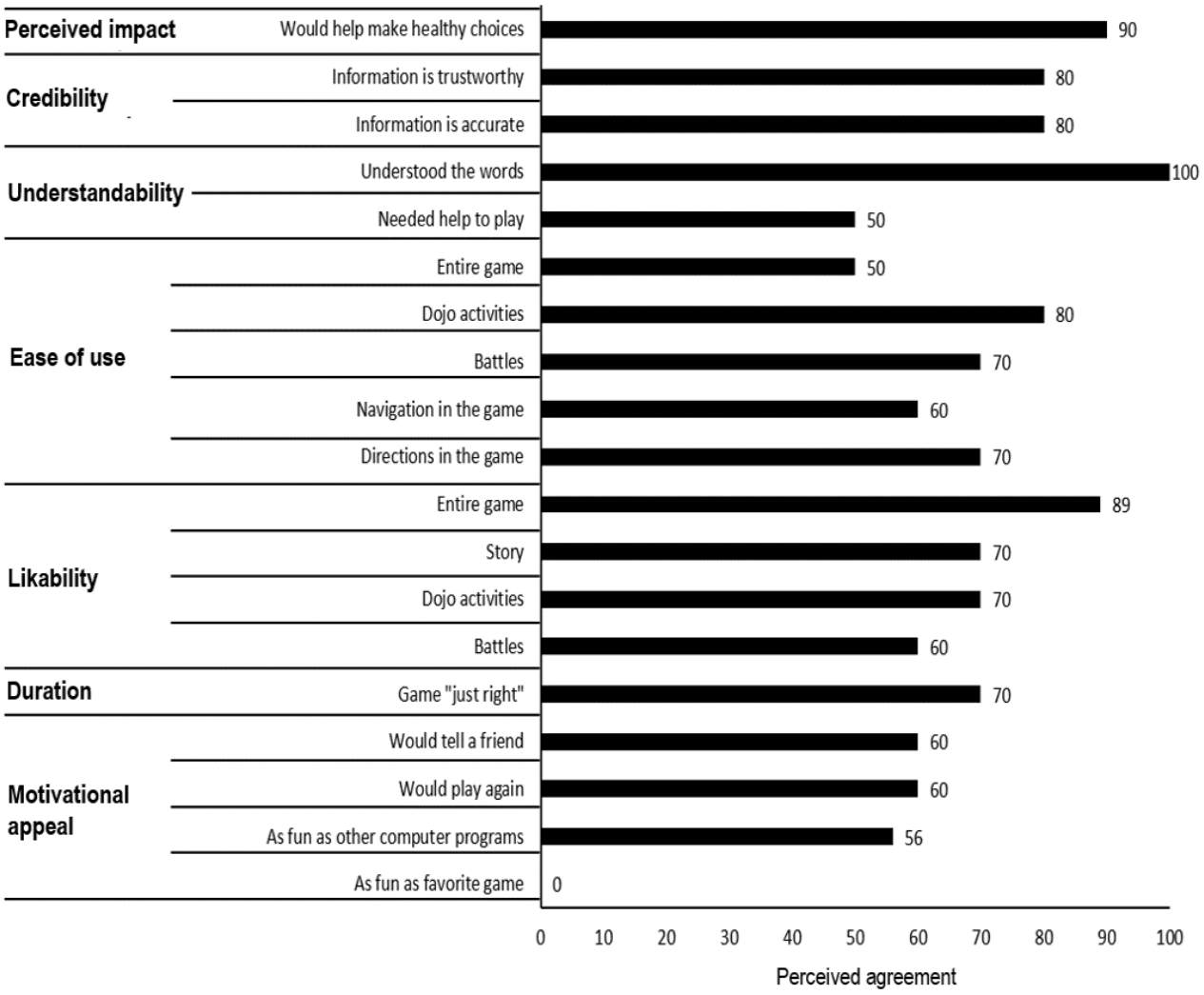
Results of Feasibility Prototype Testing

The SSS prototype functioned according to specifications with players completing the 2 levels within the 2-week period. Most young adolescents rated SSS as likable and credible (6/10, 60%-10/10, 100%) and helpful in making healthy choices (9/10, 90%; Figure 4). The prototype was rated as more fun or as much fun as other sexual health lessons (5/9, 54%), but it was not rated more favorably than favorite computer games. Conversely, less young adolescents agreed that SSS was easy to use (5/10, 50%) and indicated that they needed help to play (5/10, 50%). These lower ratings were primarily associated with technical issues (reported bugs and system *crashes*), which were a source of frustration for participants and a barrier to completing the assigned activities and led to navigation difficulties where young adolescents would lose track of their next destination in the town of Seven Stones.

Parents rated the website as likable, easy to navigate, credible, and understandable and the game as useful in helping young adolescents make healthy choices (6/10, 60%-10/10, 100%; Figure 5). Conversely, ratings of website ease of use and acceptability were lower (4/10, 40% and 2/7, 29%, respectively) as was SSS game duration (2/7, 29%).

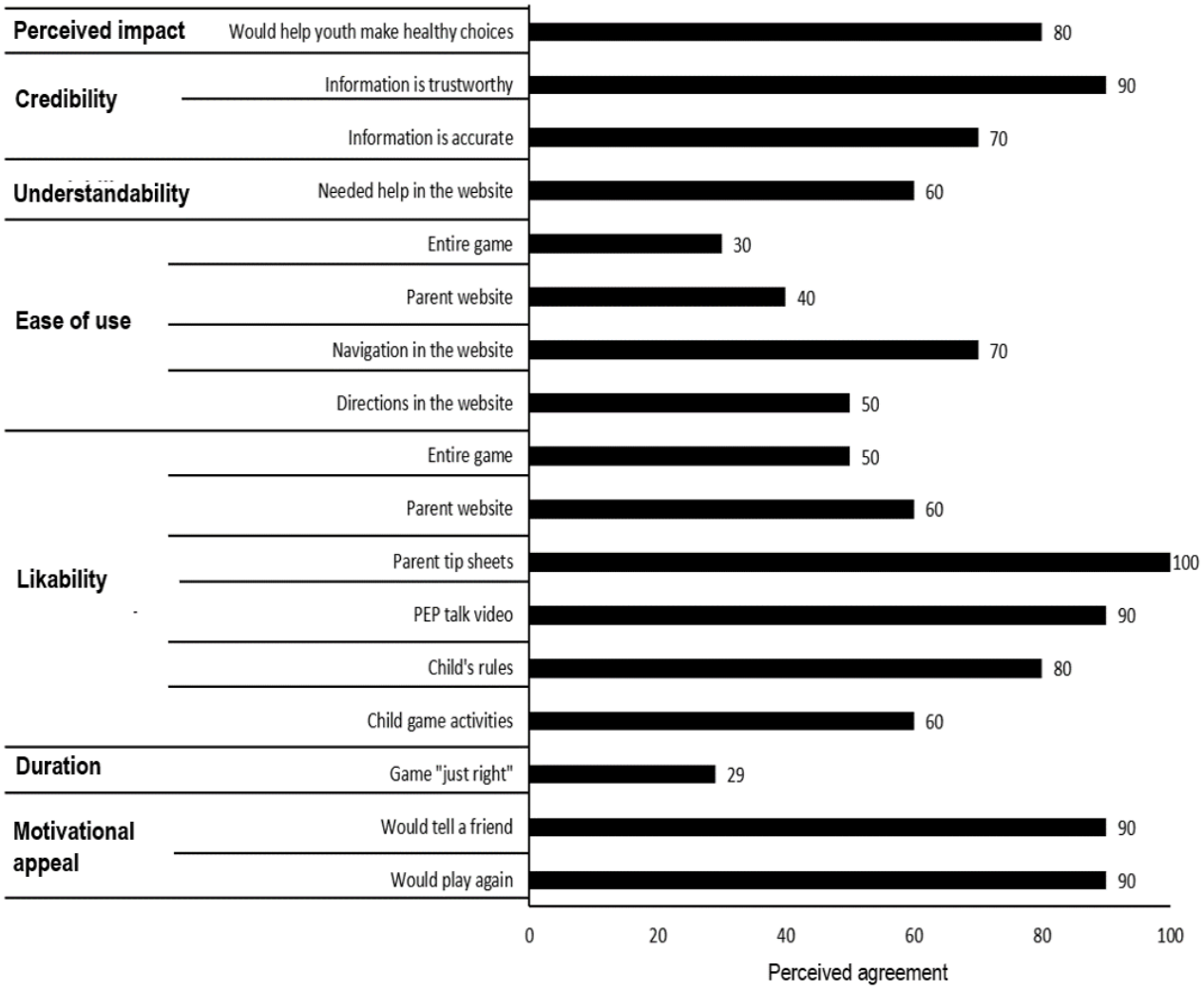
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Figure 4. Young adolescent ratings for prototype levels 1 and 2.



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Figure 5. Parent ratings for parent website and prototype levels 1 and 2.



Psychosocial Variables for Communication

Exploratory analysis demonstrated positive change in young adolescent attitudes toward using computer games for learning and parent communication outcome expectations ($P \leq .05$), driven principally by increased confidence and perceived ease of learning. Other psychosocial variables for communication were not significantly impacted within the 2-week test period (Table 5).

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Table 5. Young adolescent change in dyadic communication following exposure to Secret of Seven Stones 2-level prototype

Scales	Young adolescent					Parent				
	Baseline		2-week follow-up		P value[a]	Baseline		2-week follow-up		P value[a]
	n	Mean (SD)	n	Mean (SD)		n	Mean (SD)	n	Mean (SD)	
Attitudes to computer games for learning	*10* [b]	*1.58 (0.65)*	*10*	*1.76 (0.51)*	*.05*	N/A[c]	N/A	N/A	N/A	N/A
Communication about sex self-efficacy	7	1.35 (1.09)	9	1.67 (1.11)	.45	1[d]	2.75 (0.00)	7	2.57 (0.36)	.32
Communication about sex outcome expectation	8	2.33 (0.61)	9	2.48 (0.65)	.99	*10*	*2.31 (0.18)*	*10*	*2.47 (0.18)*	*.03*
Quality of communication about sex	8	1.91 (0.37)	7	2.01 (0.34)	.73	10	2.18 (0.25)	9	2.28 (0.29)	.07
Communication ability	10	3.80 (2.30)	9	5.22 (1.09)	.14	10	4.90 (0.57)	10	4.20 (1.40)	.15
Communication openness	8	1.43 (0.57)	8	1.41 (0.61)	.67	10	1.31 (0.21)	8	1.28 (0.22)	.72
Parent-adolescent connectedness	10	3.52 (0.57)	9	3.64 (0.52)	.85	10	3.72 (0.33)	10	3.70 (0.45)	.87

[a]Wilcoxon signed-rank.

[b]Italics indicate significance at $P \leq .05$.

[c]N/A: not applicable.

[d]Respondent data missed in web-based survey.

SSS Completion in Preparation for Implementation

Prototype testing informed our completion of the full 18-level prototype. SSS had demonstrated feasibility and compared favorably to other sexual health education programs. However, design modifications were indicated for both the adventure game and parent website. Program *bugs* and *stalls* were tracked and fixed, and the player navigation was modified. An open world architecture allowing the player freedom to move at will and explore the gaming environment, originally supported by the P-YAG, was redesigned to be a more directed sequence of destinations with more clearly articulated instructions. Parents reported website navigational problems when trying to locate the parent information associated with their young adolescent's game level, largely due to forgetting how to use the site between visits. To create a more intuitive site, visual cues that highlighted the relevant information were provided upon log-in. Printed and electronic parent guides were developed, and a web-based tutorial was included to improve the understanding of navigation.

Step 5: Plan for Program Adoption, Implementation, and Sustainability

In step 5, we planned for SSS implementation and dissemination (Table 1). We developed a commercialization plan in accordance with the STTR funding mechanism, which comprises direct-to-consumer sales and bulk licensing to intermediary organizations.

Direct-to-Consumer Sales

Parents and young adolescents in the feasibility pilot provided information on purchase interest, cost points, barriers, and facilitators for purchase and expected marketing channels. Most young adolescents (6/10, 60%) expressed interest in purchasing SSS if it was for sale. They cited potential barriers to purchase of cost (56%), uncertainty about SSS efficacy (2/9, 22%), and long play duration (2/9, 22%). Most parents (6/10, 60%) were willing to pay at least US $20 for SSS. They cited barriers to purchase of duration (5/10, 50%) and possible misalignment with their values (4/10, 40%), potential facilitators to purchase as testimony from other parents (5/9, 56%), and evidence of effectiveness (4/9, 44%). Parents (4/10, 40%) and young adolescents (5/9, 56%) expected to hear about SSS mainly through school.

Bulk Licensing

Discussions with representatives from third-party distribution channels that promote family wellness (eg, WebMD, Aetna, Humana, and ActiveHealth) resulted in awareness of the SSS proof-of-concept and interest in ongoing discussion as the product matures out of prototype through efficacy testing. Additional market analysis will use the Strategyzer strategic management framework to further develop the business model

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[88]. Ongoing customer discovery interviews will specify marketing approaches, delivery channels, and SSS modifications to address pain points (problems to be solved), gain creators (existing solutions), and value propositions (program attributes that drive a purchase decision) across all customer segments.

Step 6: Plan for Evaluation

In step 6, we planned to evaluate the SSS (Table 1). Our SSS evaluation plan comprised a randomized controlled efficacy trial with 85 parent-young adolescent (aged 11-14 years) dyads to test the full SSS game. Dyad psychosocial and communication data will be collected at baseline and at the third and sixth month. Hypotheses would be that dyads accessing SSS will report increased frequency and quality of communication about sexual health and young adolescents will demonstrate greater intentions to delay initiation of sexual behavior compared with those not receiving SSS.

Discussion

Principal Findings

The SSS represents a novel application of an intergenerational serious game for sexual health education, adding to the limited cadre of home-based programs that facilitate parent involvement in influencing young adolescent behaviors and reducing adolescent sexual risk taking [8,18,46].

SSS is an intergenerational game to the degree that it provides both parents and young adolescents' roles in the gaming experience and encourages dialogue to accelerate game play. Parents and young adolescents could sit together to play SSS, but currently the game does not allow parents and young adolescents to synchronously play or compete in the game space. Parental time constraints necessitated a gatekeeper role for parents rather than a dual-player mode. This is consistent with what Voida et al [35] have described as the *performance/audience* role pair that was pervasive in their explorative studies of intergenerational gaming. In this instance, there is a more active performer (usually the young adolescent) and a spectator role (usually the older person). The analogy is that the SSS adventure game is experienced more actively by young adolescents and more vicariously by the parent gatekeeper.

Success in serious game design is predicated on achieving a balance between strategies for behavior change and playability. This introduces a tension between ensuring sufficient educational content and optimal exposure for behavioral impact while providing an engaging and immersive experience. As a health education program, parents positively rated SSS, reporting it to be valuable and credible. The positive impact on attitudes toward the use of computer games for learning supports the utility of this strategy. The interest of young male adolescents (7/10, 70% of our feasibility sample) to play SSS, which is a population group that has traditionally been more difficult to recruit and retain in sexual health education programs, was also encouraging [28,43]. The use of a serious gaming strategy may be intrinsically motivating to this population segment, thereby increasing exposure to sexual health content [33]. Most young adolescents reported that the duration of SSS was *just right*. This is encouraging as approximately 13 hours of sexual health curricula exposure is optimal to see the impact on delayed sexual initiation [89]. Conversely, even within the limits of a 2-level feasibility test, most parents suggested that SSS was *too long* compared with *too short* or *just right* (both 29%) despite considerable design efforts to reduce parental burden. Rectifiable *bugs* in the prototype may have contributed to this perception. It is uncertain to what degree this perception translates to reduced use or attrition of young adolescents using the full SSS program.

Young adolescents rated SSS as fun as other computer games (56% agreement) but, perhaps predictably, none rated SSS as much fun as their favorite computer game. SSS exhibited common gaming features such as the quest motif, characters and bosses, virtues, power-ups, battles, and points. However, there were dissimilarities relating to the educational content, including power-up dojo activities, quizzes, parent updates, PEP talks, and skills training around life skills issues. Furthermore, SSS could not compete with the production value of high-end commercial games that feature richly textured graphics, epic musical scores, massive scope, greater user control, and sophisticated three-dimensional game mechanics. SSS, similar to other serious games for health, may best be marketed as a palatable way to consume health information and training rather than as a direct competitor to commercially available entertainment games. Health-oriented games occupy a commercial niche that offers social value and has the potential to operate in community settings with an aligned mission (eg, schools, work places, clinics). In the context of the home, where there is an array of competing demands, the use of serious games may be more tenuous and contingent on parent and child commitment.

IM is one of a number of useful development frameworks [34,90,91]. It has been applied for game-based sexual health curricula for middle school students and interventions for gay men [28-30,38,61]. As a general development framework, it has demonstrated utility in designing, developing, implementing, evaluating, and disseminating theory-based serious games and in enabling the development of interventions that provide skills training for complex health behaviors. Commercial product development, under the NIH STTR grant mechanism, represents a novel application of the IM framework despite the burgeoning trend of innovation incubators and academic-corporate partnerships. The commercial dissemination of serious games holds the promise of generating a revenue stream to sustain them. Efforts in this arena have been ongoing for over a decade; however, research on the potential for serious games in sexual health is in its infancy and exemplary models of commercial success are yet to be reported.

Limitations

The findings need to be interpreted in light of study limitations. The pilot study was formative in nature. A small sample size (n=10 dyads), abbreviated intervention dose (2 levels over 2 weeks), and the use of self-selected sampling, although appropriate in this setting for feasibility assessment, were insufficient to assess the efficacy of the game and impact on psychosocial and dyadic communication outcomes. The sample

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was inherently biased, attracting parents predisposed to improving communication with their children, and predominantly of mothers, which may have affected the parental content and resources (and hence appeal and relatability) of SSS. Our development was not powered to provide a meaningful comparison of mother and father perceptions of SSS. Mothers and fathers provided similar responses regarding the usability and feasibility of SSS (eg, that SSS was useful in helping young adolescents make healthy choices and that most parents would tell their friends about SSS). Further investigation of varied parental perspectives would be useful. It is possible that the male (father) perspective was underrepresented in the SSS development process. Postponing commencement of the field testing in favor of more extensive alpha testing may have mitigated some program *bugs* and thus some usability ratings. This is difficult to guarantee, however, and the usability data gathered was valuable despite these issues. The formative pilot testing of 2 levels, although important and useful in product evolution, inherently limited the conclusions we could offer about SSS, as it limited exposure to content topics of communication, healthy friendships, decision making, and sexual health topics that are delivered later in the game. There is a precedent in previous school-based studies to indicate that the content scope and volume is appropriate for the young adolescents, but this remains to be further empirically tested within the home context [28,29,31]. Dyads were not challenged to start having conversations on topics that traditionally cause greater discomfort, a necessary focus for the efficacy study. Program-led discussions are not always well received if they are perceived as *contrived* or *forced* and not organic. Thus, naturally occurring conversations are preferred. Future studies will focus on how parent-young adolescent dyads perceive PEP talks and whether these can promote naturally occurring discussions beyond any need for program cues. Despite limitations, the exploratory results were consistent with the content covered and indicative of the potential of exposure to the full program. The criteria by which developers pilot and field test complex interventions can vary as a function of scientific, resource, and timeline constraints, but guides exist to assist in decision making and determining evaluation designs. In this regard, a useful adjunct to IM is the United Kingdom Medical Research Council guidance document on developing and evaluating complex interventions, providing consideration of study designs with case study examples [91].

Important empirical questions remain regarding SSS. SSS allows families to choose the *match* of parent-young adolescent dyadic combinations (mother or father with daughter or son) based on existing communication dynamics, desire, and logistics. Young adolescents may prefer same-sex caregiver support for sexual health discussions. Further studies pertinent to the field of intergenerational gaming could investigate the differential benefits of alternate dyadic combinations, triadic combinations, and inclusion of siblings in improving communication and family dynamics. Altering the game mechanics to allow for text messaging updates and prompts for 2 parents and adjusting the expected communication dynamics to be inclusive of *parents* and young adolescents are relatively easy adjustments. Future studies could also contribute to our understanding of the *optimal* exposure to achieve behavioral impact.

Conclusions

SSS provides a feasible strategy to overcome parent and young adolescents discomfort about discussing sexual health topics and enhancing the skills required to initiate and maintain this dialogue. IM is a useful framework for developing a theoretically and empirically based intergenerational, sexual health computer game (SSS) for in-home use. Further testing to assess the efficacy of the complete SSS program on parent-young adolescent communication is indicated.

Acknowledgments

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Conflicts of Interest

None declared.

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Abbreviations

HPV: human papillomavirus
IM: intervention mapping
LGBTQI: lesbian, gay, bisexual, transgender, queer, and intersex
NIH: National Institutes of Health
PEP: partner-engage-plan
PRECEDE: predisposing, reinforcing, and enabling constructs in educational diagnosis and evaluation
P-YAG: Parent-Youth Advisory Group
SSS: Secret of Seven Stones
STI: sexually transmitted infection
STTR: Small Business Technology Transfer Research

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Original Paper

The Development of an Escape Room–Based Serious Game to Trigger Social Interaction and Communication Between High-Functioning Children With Autism and Their Peers: Iterative Design Approach

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Abstract

Background: Children with autism spectrum disorder (ASD) have social deficits that affect social interactions, communication, and relationships with peers. Many existing interventions focus mainly on improving social skills in clinical settings. In addition to the direct instruction–based programs, activity-based programs could be of added value, especially to bridge the relational gap between children with ASD and their peers.

Objective: The aim of this study is to describe an iterative design process for the development of an escape room–based serious game as a boundary object. The purpose of the serious game is to facilitate direct communication between high-functioning children with ASD and their peers, for the development of social skills on the one hand and strengthening relationships with peers through a fun and engaging activity on the other hand.

Methods: This study is structured around the Design Research Framework to develop an escape room through an iterative-incremental process. With a pool of 37 children, including 23 children diagnosed with ASD (5 girls) and 14 children (7 girls) attending special primary education for other additional needs, 4 testing sessions around different prototypes were conducted. The beta prototype was subsequently reviewed by experts (n=12). During the design research process, we examined in small steps whether the developed prototypes are feasible and whether they have the potential to achieve the formulated goals of different stakeholders.

Results: By testing various prototypes, several insights were found and used to improve the design. Insights were gained in finding a fitting and appealing theme for the children, composing the content, and addressing different constraints in applying the goals from the children's and therapeutic perspectives. Eventually, a multiplayer virtual escape room, AScapeD, was developed. Three children can play the serious game in the same room on tablets. The first test shows that the game enacts equal cooperation and communication among the children.

Conclusions: This paper presents an iterative design process for AScapeD. AScapeD enacts equal cooperation and communication in a playful way between children with ASD and their peers. The conceptual structure of an escape room contributes to the natural emergence of communication and cooperation. The iterative design process has been beneficial for finding a constructive game

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structure to address all formulated goals, and it contributed to the design of a serious game as a boundary object that mediates the various objectives of different stakeholders. We present 5 lessons learned from the design process. The developed prototype is feasible and has the potential to achieve the goals of the serious game.

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KEYWORDS

serious game; autism; design research; boundary object

Introduction

Background

Autism spectrum disorder (ASD) is a neurodevelopmental disorder. Children with ASD often face difficulties in initiating and maintaining conversations and find it challenging to interpret verbal and nonverbal behavior, which commonly leads to misunderstanding the intentions of others [1-4]. Children with ASD often do not spontaneously interact with peers and have difficulty making eye contact [5-7], often struggle to make friends [8], are more likely to be excluded by peers [8-15], and are more likely to be victims of peer harassment [16]. Many interventions developed for this target group focus on improving and training social skills [17]. One of the goals of social skill training is to enable these children to better cope with their peers. Although social skill training interventions demonstrate improved social skills in clinical settings, the developed social skills in training are not necessarily applied in children's daily lives at school [18,19]. In addition, improving social skills does not necessarily mean breaking the negative bias of peers at school [20], which affects the quality and quantity of relationships.

The difficulties children with ASD face in forming and maintaining relationships with peers can lead to social fragmentation at school [21]. Research suggests a discrepancy in the quality and quantity of relationships reported by children with ASD compared with peers [22,23]. Some research even suggests that these children have the fewest friendships of all disabled groups [24]. In addition, according to the children themselves, they do not necessarily link how developing social skills contributes to forming more friendships and greater acceptance by peers at school [25]. Although one of the goals of social skill training is to better cope with peers, and social skills can improve in training, its effects do not always transfer to practice. Interventions that incorporate the peer-group context in natural settings can be beneficial for improving social skills [26] and improving relationships [27]. Nevertheless, there are very few interventions that focus specifically on this issue.

Serious Games as Activity Context

Mutually enjoyed activities that focus on similar interests can be a fitting way for individuals with ASD to connect with others [28,29]. Therefore, activity-based interventions might be preferable for individuals with ASD than instruction-based interventions [28]. Activity-based interventions provide structure and a concrete focal point, allowing interactions to unfold more naturally [30]. Children with ASD seem to have an affinity toward digital technologies owing to their linearity and discreteness and often play video games themselves [25,31]. Several studies indicate that games can provide an enhanced experience compared with more common instruction-based interventions and teaching methods [32-34]. Games offer unique features to motivate, trigger, personalize, and facilitate learning [35,36] and provide a safe context for practicing more complex skills [37]. Furthermore, games can provide immediate and consistent feedback for children with ASD [38].

In autism research, there is great interest in the application of games to pursue therapeutic goals. Within the spectrum of games, a distinction can be made between interventions that gamify certain elements and interventions aimed at providing a good gaming experience. Interventions such as *LIFEisGAME* [39], *Secret Agent Society* [40], *Let's Face It!* [41], *A Sunny Day* [42], and *TeachTown* [43] are based on a gamification approach, offering a reward system for finishing more traditional therapeutic tasks. This approach has 2 concerns: (1) although game elements and therapeutic tasks are combined, they do not provide a coherent experience [44], which is known as fidelity dissonance [45], an incongruence in in-game concepts that causes a disturbance in the game experience, and (2) compared with video games on the market, these interventions offer a poor game experience, which might undermine children's interest in playing [44].

Interventions that facilitate collaboration and social interaction within a more integrated game design are *Invasion of the Wrong Planet* [46] and a technological touch-activated Collaborative Puzzle Game [47], offering an environment to collaborate through puzzling. *Pico's Adventures* [44] is a game based on full-body interaction to promote social initiation skills. Another example of a serious gaming intervention is Lands of Fog [48,49]. Lands of Fog is a multiuser experience, designed with and for children with ASD to foster social initiation and collaborative behaviors. Within Lands of Fog, players can explore and discover unique characters, objects, and events in a magic world by catching fireflies. The game offers an immersive environment and provides specific mechanics to foster collaboration. This game appears to be a useful instrument to facilitate conversation and promising to promote engagement, socialization, and collaboration [48], which can positively affect children's lives at school and their relationships. The game was able to unite children with and without ASD through an enjoyable and informal common activity–based experience. The practical disadvantage of Lands of Fog is that it is difficult to implement widely in terms of equipment and the required physical space. The system is structured in a 6-meter circular arena, where a virtual world is projected on a floor.

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Escape Room as Activity-Based Experience

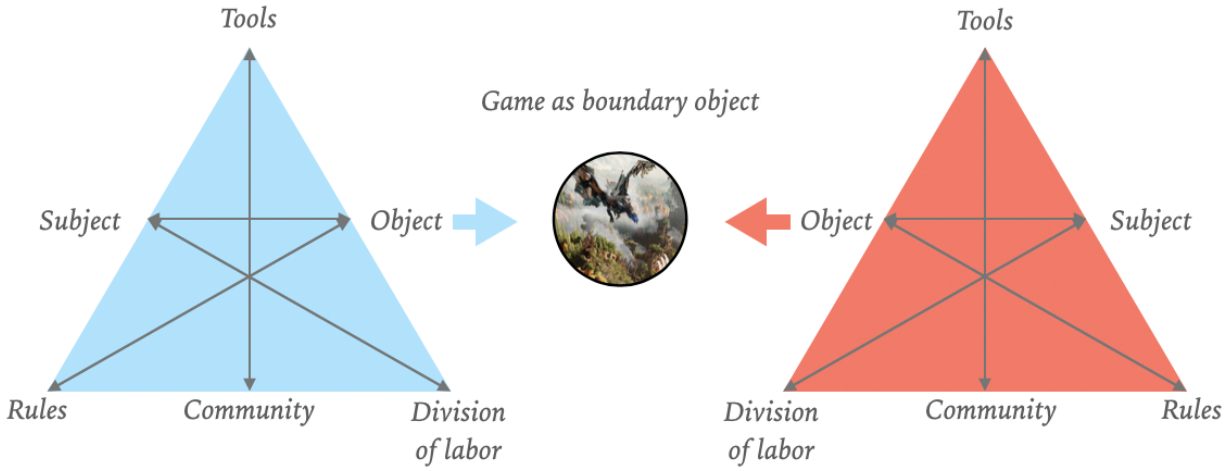
Since its inception in Japan in 2007, escape rooms have been growing in popularity worldwide [50]. Entertainment-focused escape rooms are now available across most continents, including Europe, Asia, and America. In escape rooms, participants are given a scenario where they discover clues and solve puzzles to accomplish a specific goal in a limited time, usually escaping the room [51-53]. Participants often must work together and collaborate to fulfill different tasks successfully. Although research into the impact of escape rooms is still limited, escape rooms have already been used for various serious and learning-related purposes [54-57].

Due to the cooperative and game-like nature of escape rooms, escape rooms seem suitable for providing an informal activity–based experience for training social behavior and collaboration. Escape rooms are immersive and engaging [58], and the concept of puzzling and collaborating is fitting to integrate into a serious game. An escape game might offer a natural setting for players to communicate with their peers and can provide an emerging experience. This might allow interactions to unfold naturally. If properly designed, an escape game can offer a fun experience based on equivalent interactions and relationships, which is conditional on achieving friendships and acceptance among peers [27].

A Serious Game as a Boundary Object

When designing a game with serious purposes, addressing the oxymoron and uniting the fun with the serious aspect is essential but challenging. Mapping out the various stakeholders' perspectives and goals is often a necessary step because the interest of the fun element and the interest of the serious part is usually divided among stakeholder groups, especially when designing serious games for children. Experts who facilitate social skill training programs are interested in pursuing specific therapeutic goals. At the same time, children want to establish better relationships with their peers and, above all, seek a fun experience in a game. To overcome this lack of consensus, the concept of boundary objects can provide a perspective. The idea of boundary objects, which is growing in interest [59-63], was initially framed to facilitate constructive cooperation between sides or social systems in the absence of consensus [64]. Boundary objects [65] can fulfill an important function in overcoming boundaries by addressing and adapting the local needs and constraints of different stakeholders. As an in-between object, the boundary object belongs to the worlds of both stakeholder groups (Figure 1).

Figure 1. A game as a boundary object.



In the example of social skills training for children with ASD, children with ASD and experts who facilitate social skills training are connected and have a shared concern. Both parties are interested in making children function better in social situations; however, children have different goals than experts. Experts mainly focus on improving social skills, whereas children want to establish better relationships with their peers [25]. A well-designed serious game can be a novel platform to facilitate communication and a medium that strengthens relationships between sites [66] by creatively adapting and addressing user needs. Designing a serious game as a boundary object ensures that different stakeholders' needs are addressed, which facilitates an inclusive design. The active inclusion of children's goals and children with ASD is essential in designing a fitting serious game [44].

Aim

This paper describes an iterative design process for the development of an escape room–based serious game. The purpose of the serious game is to facilitate direct communication between high-functioning children with ASD and their peers, for the development of social skills on the one hand and strengthening relationships with peers through a fun and engaging activity on the other hand. During the design research process, we examined in small steps whether the developed prototypes are feasible and whether they have the potential to achieve the objectives of the serious game. This paper aims to provide insight into the design process and describe the development of a serious game as a boundary object.

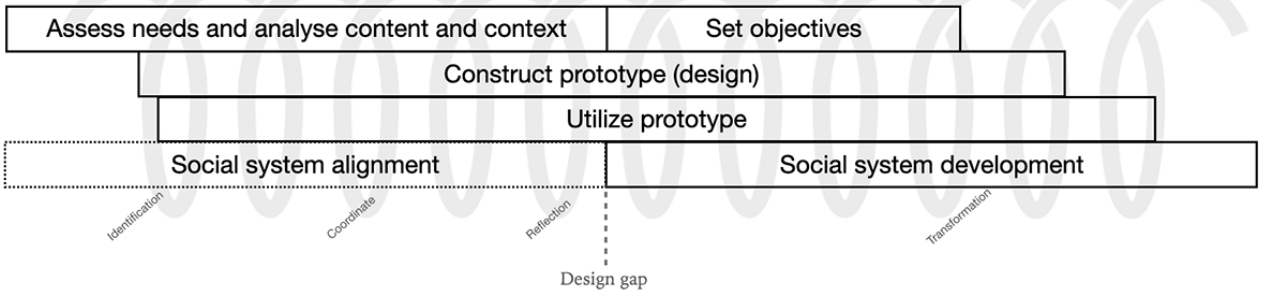
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Methods

Study Design

This study is structured around the Design Research Framework (DRF; Figure 2) [67,68]. This framework facilitates the development of serious media interventions and serious games through an iterative-incremental process. The focus of these iterations shifts during the process, along with the nonlinear design steps [69].

Figure 2. Design Research Framework.



The DRF gives direction within a design process on a more transversal level and can provide insight into where the focus in the development of an intervention lies. In our earlier research [25], we focused on assessing needs and analyzing content and context; this study focuses mainly on the construction and utilization of prototypes.

Various participatory design activities have been conducted to make the boundary object perspective applicable to the design process. As a boundary object, the serious game has to address both the therapeutic goals and needs as children's needs while still being fun and engaging. Children with special needs can benefit from an inclusive design approach [70]. However, in practice, participation sometimes remains superficial and participatory design activities end up in sessions where children are mainly responding to, for example, visual aspects. Malinverni et al [44] proposed an inclusive design approach specifically for developing video games for children with ASD, where children and experts both provide input of specific elements that translate to game elements. Although the organization and structuring of sessions were slightly different in this study, this has been one of the central principles in the design process.

Children's Perspective

For children, forming more friendships, connecting with peers, and experiencing more acceptance by peers at school are important goals [25]. To achieve this, equality is considered an important principle. Equality is essential in forming relationships and friendships among children with ASD [27]. Further, mutually enjoyed activities that focus on similar interests can be a fitting way for individuals with ASD to connect with others [28,29]. A serious game that initiates social interaction in a structured way might be an appropriate way to address this issue. To arouse children's and their peers' interests, the game should also offer a fun and engaging experience. In addition, children provided input in finding an appealing theme and narrative for the game.

Therapeutic Perspective

On the basis of an existing social skills training protocol, as described by Dekker et al [71], and literature on joint attention [72], 4 therapeutic goals have been taken as the guiding principles throughout the design process. These goals are turn-taking, cooperation, joint attention, and vocalization. The application and expression of these goals within the prototypes can be considered as the *early predictors of success* [73]. These principles guide the evaluation of the prototypes.

Timeline

The sessions and activities described in this study took place within a 40-week school year, which runs from September to halfway through July. In this research, 4 iterations are described, consisting of developing and testing prototypes. The first 3 iterations were conducted within the first 20 weeks, always in a block of approximately 3 weeks. During the first 3 iterations, the authors developed the prototypes in 1-2 days and then tested the prototypes around schoolwork at various times within 3 weeks at schools. There were test periods and school breaks between the iterations, which made testing on location impossible. The final prototype was developed in 14 weeks by a professional development team, including the time required to form the team. This prototype was then tested with children and experts between June and July.

Participants

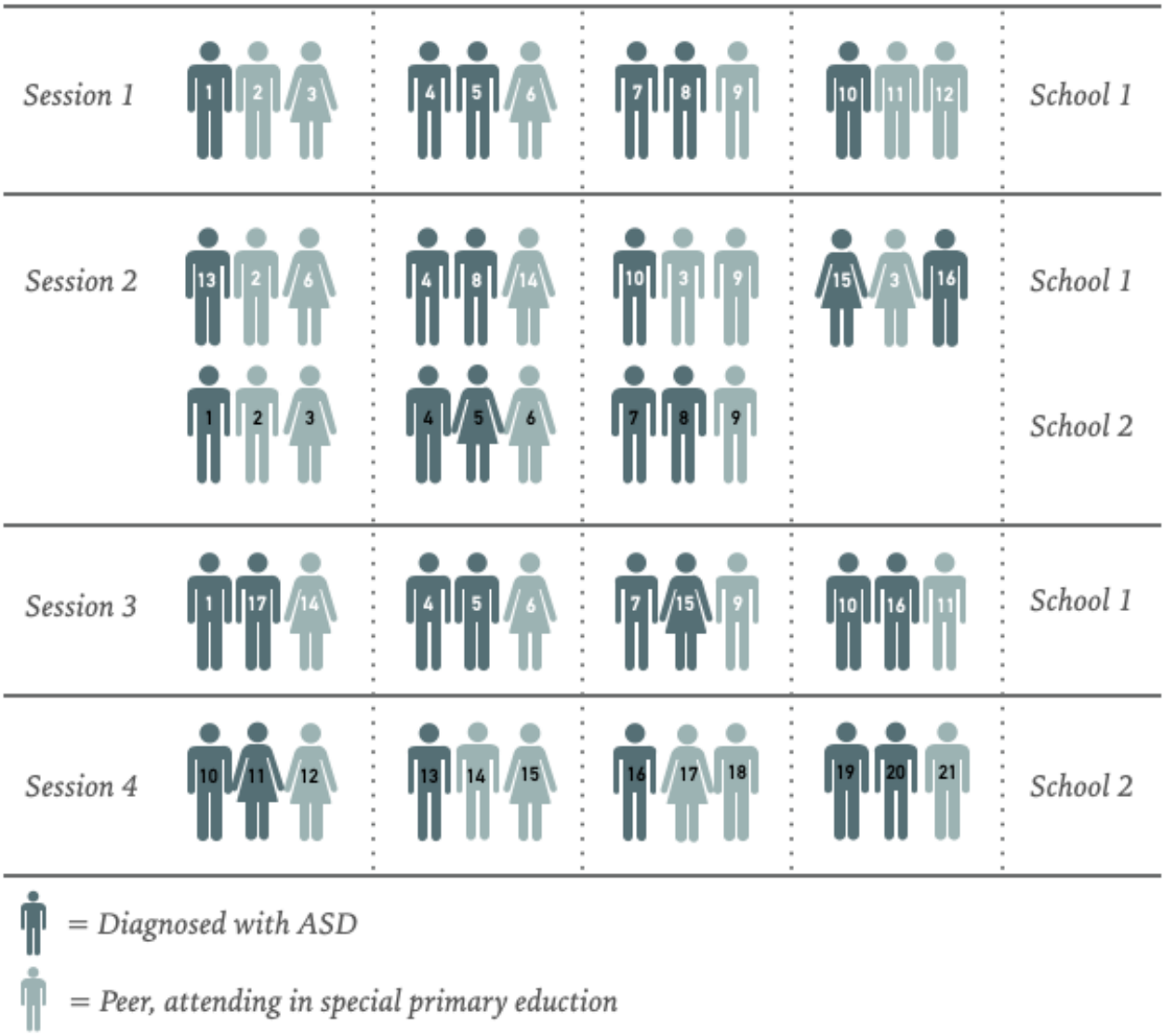
Children

For the recruitment of the children, 2 special primary education schools participated. In the Netherlands, schools in special primary education have the same core objectives and curricula as that of regular primary schools. However, special primary education schools offer extra help to children with additional needs. The groups in special primary education are smaller, and there are more teachers and experts to assist the children. In the Netherlands, only children with additional needs attend a special primary education school. Those are children who are able to follow a regular primary school curriculum with some additional support, with the majority subsequently progressing to regular secondary education. In total, 3 classes functioned as pools for the sessions. Throughout the sessions, children diagnosed with ASD and their peers participated. The children with ASD have all been diagnosed with high-functioning autism. In total, 37 unique children participated in the study, 12 were girls and 25

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were boys. A total of 5 girls and 18 boys were diagnosed with ASD. All children were aged between 10-12 years. Figure 3 shows an overview of how the pools' participants had a place in specific sessions.

Figure 3. Participating children per session. ASD: autism spectrum disorder.



For considerations around privacy and ethics, more specific diagnostic characteristics of the children have not been documented, as have the other children's medical and psychological backgrounds. For this research, which focuses on the feasibility of the prototypes to pursue specific goals, this personal information adds relatively little in this stage. The children and their parents provided informed consent. All retrieved data were processed anonymously.

Experts

A total of 12 experts were consulted to provide their input. The experts were connected to the project through participation requests within their organizations. The experts work in the field of child psychiatry (n=8) or at special primary education schools (n=4) and are familiar with the target group and regular social skill interventions for children with ASD. The experts provided informed consent. All retrieved data were processed anonymously.

Evaluation

In this study, 4 prototypes were tested in children. After the first test, a creative workshop was held to let children brainstorm about the theme of the escape room. We started with a paper prototype supported by materials from an existing escape room board game and ended with a multiplayer serious game playable on Samsung Galaxy Tab S2 tablets. On the basis of the different goals, the prototypes were evaluated after each test. Test sessions with children were also used to test the puzzles. The goal was to compose puzzles that were challenging and at an appropriate level for the specific age group of 10 to 12 years, by evaluating whether or not children can complete each puzzle given the information presented without any extra hints.

In the fourth test session, we also used the Playground Observation Checklist [74] to evaluate the play behavior. Although this checklist comes with some considerations and more background information on the children would be essential to make a reliable interpretation of the observation, the

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Playground Observation Test is a useful operationalization of social play behavior. In this phase of the study, the observation list was used to determine whether there were significant differences between playing behaviors among children playing the prototype.

Results

Overview

All tests have been carried out at the special primary schools. As there was always a larger pool of children present at the schools during the tests, there was no difference in the number of participants reported, as described in the *Methods* section.

Iteration 1: Prototype 1 and Creative Workshop

Prototype

Prototype 1

For the first test session, an existing board game was used—*Mission: Escape* (Figure 4). This game is suitable for children aged 7 years or more and is based on the basic principles of an escape room concept. Within Mission: Escape, children must stop a timer with 2 keys before the predetermined elapsed time reaches 0. Children do this by retrieving 1 key out of a cage (Figure 5) and by retrieving a second key by solving multiple-choice riddles. The players can fill in the answers of the puzzles on a supplied artifact (Figure 5). After 3 correct answers in a row, the players obtain the second key.

Figure 4. Board game—Mission: Escape.



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For the test session, some adjustments were made to the game. Within the base game, the riddles of the game are presented on small cards. The base game can be played around a small table and is suitable for one or more players; however, the small cards do not encourage a collaborative game. Cooperation is an essential goal of the prototype developed in this study. To make collaboration more critical in gameplay, we separated the riddles and answers and printed them on small posters (Figures 5 and 6). By hanging the posters through the room in different spots, players must first connect the puzzle's information to solve it.

Figure 5. Materials of Mission: Escape.

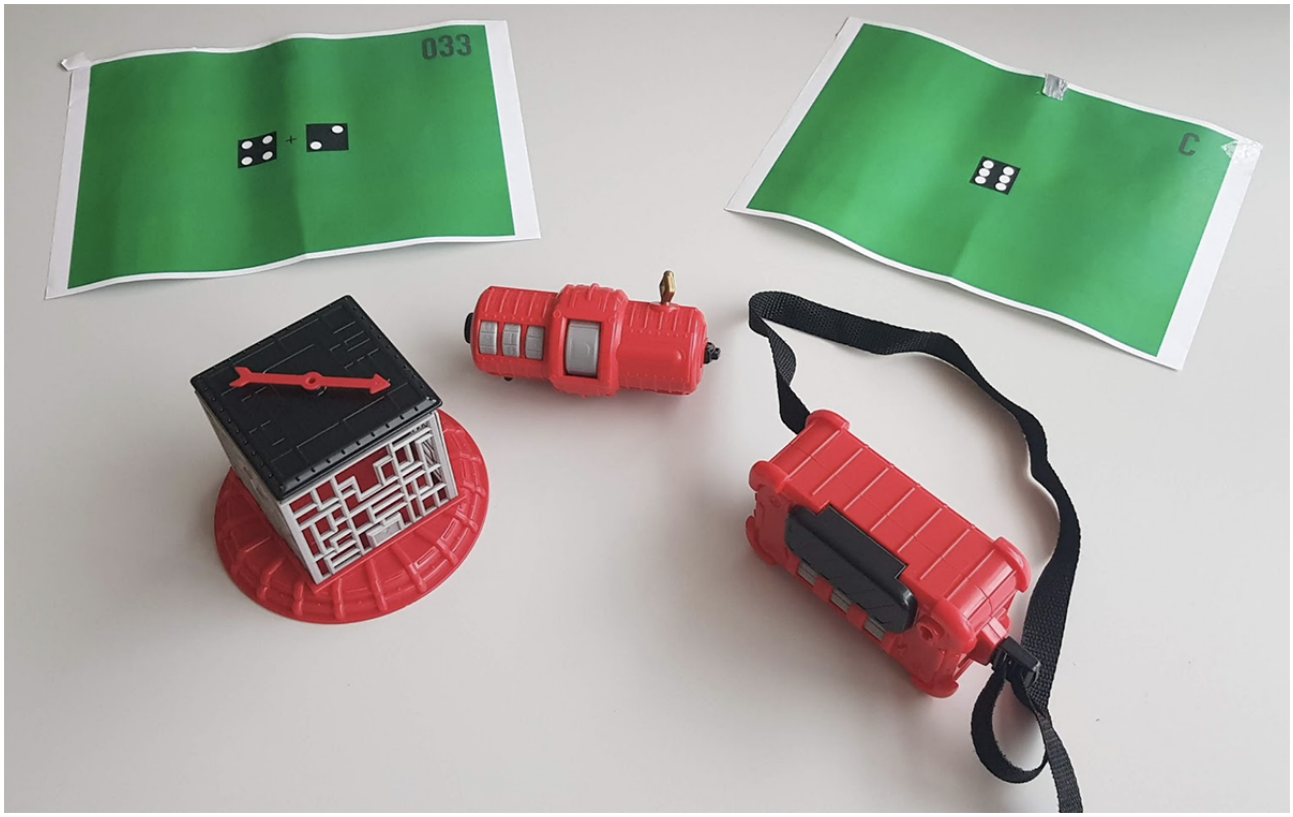


Figure 6. An example of a riddle.



Results: Test Session 1

During the first test, the mechanism with the ticking timer in all groups led to immersion and great motivation among the children during play. Children went straight to work and were motivated to solve the riddles as quickly as possible. The puzzles appeared to be solved relatively quickly for the children, and the children had only a little challenge in solving the puzzles. It took children, on average, 12 minutes to stop the timer. Although the puzzles were scattered in parts throughout the room, what should provoke cooperation, we noted that there was 1 child in all groups who claimed a very dominant role in the course of the game. This child took charge of the game and gameplay. The other children were involved in the game but more to locate specific answers—*Where is the red poster with a 4?*—and then from an equal level of influence to the game and gameplay. Although children seemed to have a fun experience and celebrated finishing the game together, one child's dominance was not very constructive in pursuing different goals, especially turn-taking and equal cooperation.

Creative Workshop

After the play session, the children were asked to work out an idea for an escape room themselves, using drawing materials. Subsequently, each child briefly presented his or her concept. After the presentations, the drawings were put on the table, and the children could hand out stickers for the idea they liked the most. The children divided 6 stickers on maximum 3 designs. This workshop aimed to identify appealing themes for an escape room.

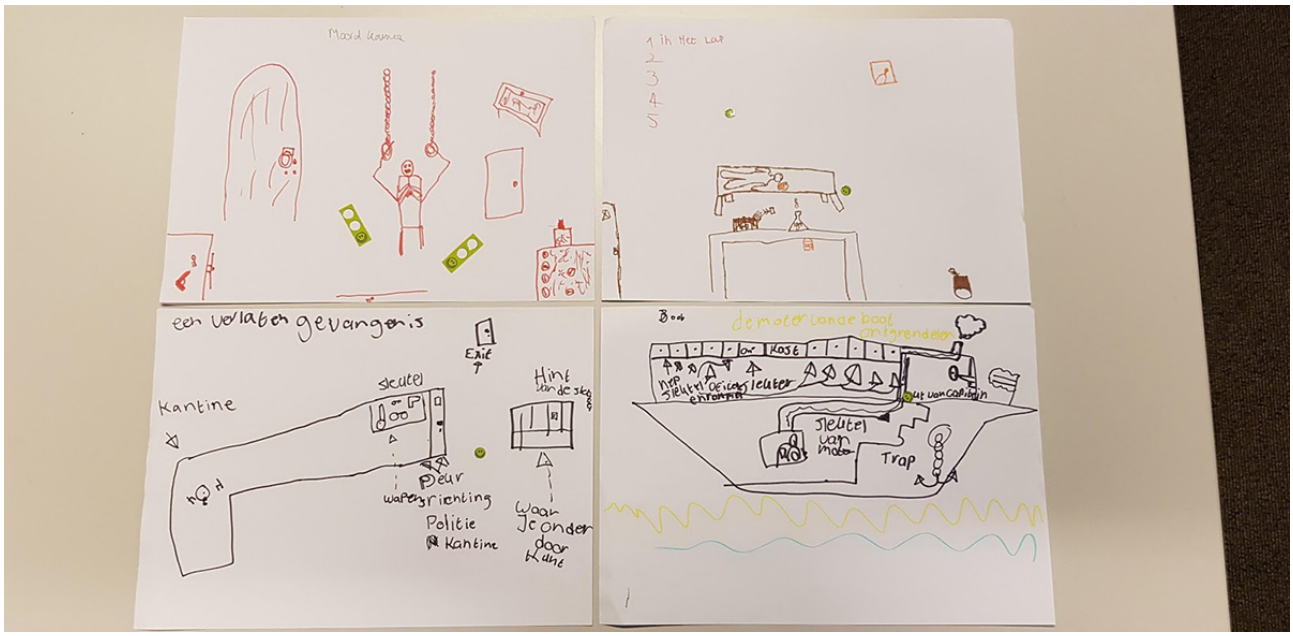
Results: Creative Workshop

During the creative workshop, all children designed an escape room with drawing materials (Figure 7). The emphasis was primarily on the theme of the escape room that they would like. The setting of the drawings varied significantly; however, besides a boat, most children chose a darker theme, such as a

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dungeon, murder room, basement, chemistry laboratory, and prison. In the sessions with the different groups, these were also the drawings that received the most votes from peers, with the murder room and dungeon being the most popular. As an explanation, children explicitly indicated these themes that were the most exciting for an escape room. Or as one child put it, "from a room like this, you want to escape very quickly."

Figure 7. Impression of drawings in a creative workshop.

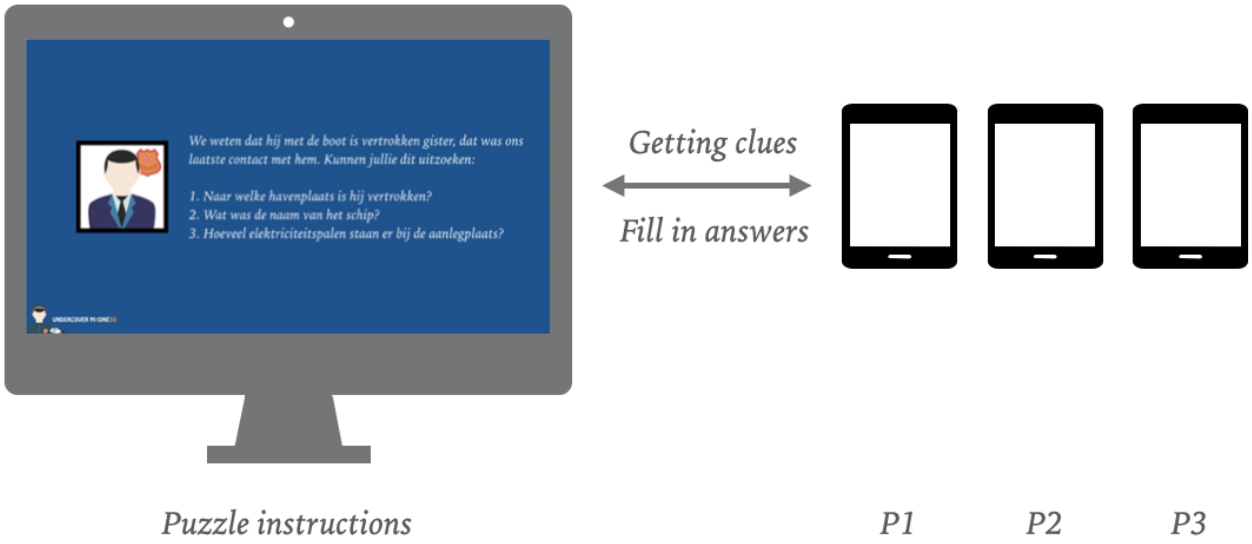


Iteration 2: Augmented Reality Prototype

Prototype 2

For the second test, a simple prototype based on augmented reality (AR) technology was developed. The prototype is an app that deploys simple 3D models on real-world triggers. The app uses the camera's input to present the real world and the layer with the 3D model simultaneously (Figure 8). The app was developed with Unity in combination with the Vuforia plug-in.

Figure 8. Setup for prototype 3.



Next to the AR app, a simple web-based environment has been created, which presents the puzzles. During play, 1 player gets the main question of the puzzle; the other 2 players must search the correct 3D model to find the answer, for example, "How many floors do the two apartment complexes have combined?" The player with the web interface communicates the puzzle to the other players. The other 2 players search for an apartment complex, count the floors, and share their answers to the player with the web interface. The player with the web interface fills in the solution, and if the answer is correct, the next puzzle appears. During play, players swap their tablets twice. This makes sure that each of the 3 players is *the commander* in one stage of the game. The web interface communicates the moments for swapping the tablets. As each of the *scanning*

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players can only scan half of the posters, they are forced to work together.

The choice of the medium and structure of the game was the result of the experience from the first iteration. By distributing the information divided among the tablets, the players are more dependent on each other and have to collaborate and exchange information more, which appeals to their collaboration and turn-taking skills. The goal of this test was to evaluate whether the players would collaborate more if the essential information was divided among the tablets and whether the players had an equal share through changing roles. For this prototype, we composed new puzzles, and the test was used to assess whether the children understood the puzzles.

Results: Test Session 2

The 3D models that the children could see through the AR technology caused many positively surprised shouts in the first phase of the game, for example, "Wow, this looks cool!" In all play sessions, the children spent the first 3-7 minutes to scan as many triggers as possible to discover all the different 3D models. When there was nothing left to check, the focus of the children shifted to solving riddles.

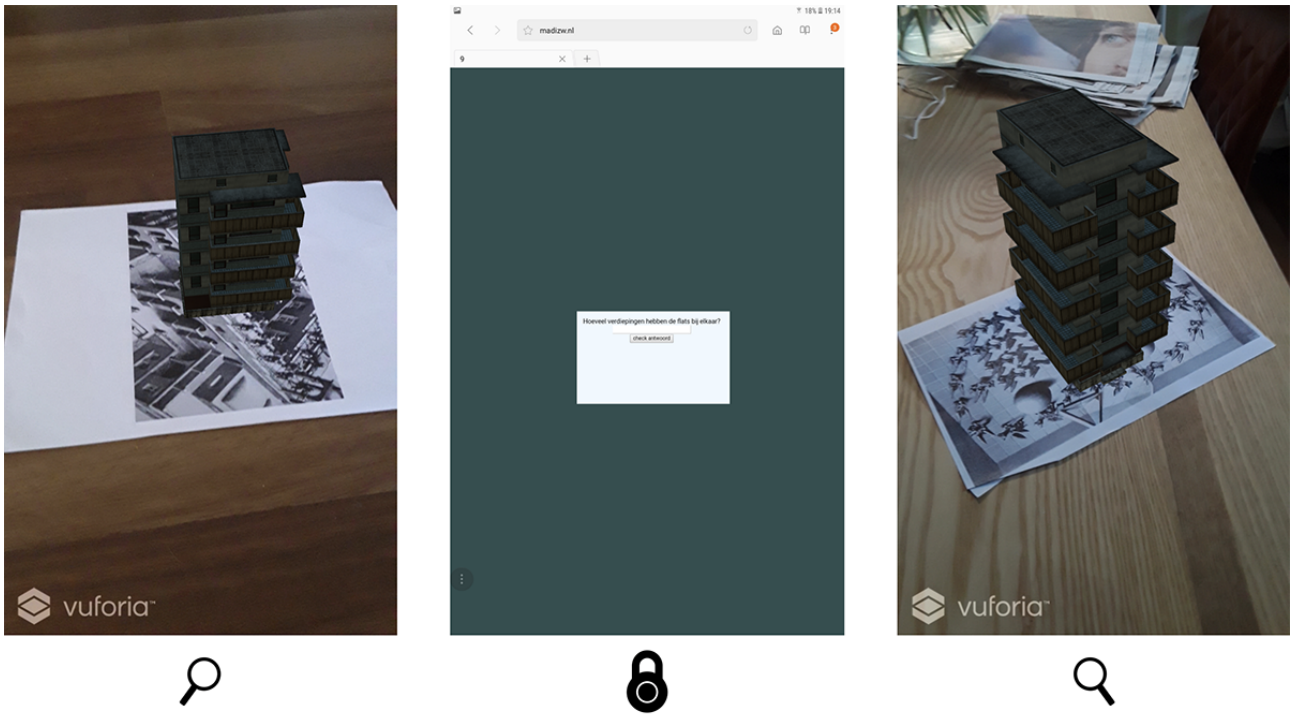
The game sessions mostly started with a good balance in cooperation and communication, where all children had an equal role. However, after a while, when the game advanced, the applied mechanism again resulted in a situation where 1 player became increasingly dominant. In all sessions, this was the player with the riddles on his or her tablet, and it manifested itself in the later stage of the game. As the second and third children who received the tablet with the puzzles had previous knowledge of where specific models were located, those children happened to become more and more direct and commanding in their communication. It did not matter whether this was a child with or without ASD. The fact that the children could walk freely in the room reinforced this. It often happened that the player with the tablet with the riddles dragged other children along to different corners of the room to guide them to the 3D model belonging to the puzzle. Although the children were very motivated to solve all puzzles and were happy when they reached the end of the game, the deployment of mechanics to enhance turn-taking and equal cooperation during the whole game was still something to improve. However, it was better in the first phase of the game than in the playtests of the first prototype.

Iteration 3: AR Prototype With External Puzzle Instruction

Prototype 3

The third prototype was based on the same principles and technology as that of the second prototype. The AR app operates in the same manner. The web interface was replaced by a television screen that presented the riddles using a laptop with a keynote presentation (Figure 9). As, during the previous iteration, the cooperation started in an equal manner but was later disturbed by the insider knowledge of players who later became commander, in this prototype, it was decided to have the puzzles presented by a neutral medium.

Figure 9. Augmented reality prototype.



After a short story that introduces a scenario, the game starts. The story was introductory to a scenario in which children were asked to reconstruct a missing undercover agent's timeline and eventually find the agent's location. Within this prototype, all 3 players are searching for 3D models, and the players do not have to exchange tablets during the game. When the players have found the clues belonging to the puzzle and have the answer to it, one of them stands in front of the television screen and speaks out the answer. A moderator checks the answer, and if the answer is correct, he or she will ensure that the next riddle

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is presented. The triggers in the third prototype were distributed over the 3 tablets, which meant that each player had precisely one-third of the necessary information to solve the puzzles. The main goal was to check whether the new mechanics led to a more equal play among the players.

Results: Test Session 3

The narration turned out to provide extra focus and motivation for the children. It was found that the children were well immersed in the story. After one session, which could not be fully completed because of time constraints, 1 of the children came back to ask if it had all worked out well in the end for the missing policeman.

The new mechanism of offering riddles ensured more balanced cooperation. None of the children became very dominant during play in the different game sessions. However, the mechanism also resulted in sessions where children often worked side by side instead of with each other. As the riddles were presented to all players at the same time, less exchange and communication was needed. Each player read which part of the puzzle he or she could solve; searched for the 3D model belonging to the puzzle; and then, only, in the last step, while sharing his or her part of the answer, came to interact with the other children. This led to a very task-oriented collaboration. Turn-taking took place more naturally in terms of goals, and the players had a more equal role in the game. However, there was hardly any communication during cooperative play.

Iteration 4: Beta Prototype and Evaluation

Beta Prototype

For the last session, the beta prototype of a serious game named AScapeD was developed (Figure 10). Within the game, the players work as detectives on the case of a missing girl named Charlotta. The players are introduced into the case with a short story, and then they are placed in the girl's room. All the rooms have the same appearance; however, each room's time is different for each player; therefore, there are various objects placed in other places. By solving riddles and bringing together information from different rooms, players advance through the game. On the basis of previous iterations' experiences, we decided to create a digital room because it makes it easier to create 3 unique rooms, each with their own pieces of the puzzle (Figure 11). This ensures that children have to collaborate and prevent a child from becoming dominant in the game based on previous knowledge. The design also ensures that the children have an equal role; each player is equally important in completing the game.

Figure 10. In-game screenshot of AScapeD.



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Figure 11. A 3-player setup of AScapeD.



Most puzzles for this prototype are constructed so that each time another player gets the first clue, often by a blinking object in the room. This player needs to catch up with the other players by describing what they see because such specific information usually contains one or two clues for the other players to find the information belonging to the puzzle to solve it. This way of constructing the puzzles triggers collaboration skills, turn-taking, and vocalization. For the 3 puzzles, the object begins to blink simultaneously in all the rooms. These 3 puzzles are based on classic games. Within 2 of these games, players take turns within the game. These are a mastermind game and a classic car sliding puzzle. The third game, a classic sliding puzzle, is solved by each player individually.

During the game, players find 3 fragments from the girl's diary: one from the morning, one from noon, and one from the early evening. Players learn that Charlotta feels a little bit lonely at school and does not connect very well with her peers. Eventually, she would run away to the cottage of her grandpa in the forest because her grandpa is always helpful and understanding.

The choice for a digital version of an escape room is to keep the context of use flexible. We found out with earlier prototypes that there is a practical constraint in the spaces we could use. Many special primary schools do not have the facilities to set up a larger room for an intervention for a more extended period. For extra support or interventions within these schools, you often have to use small offices. The 3 tablets make the context of use flexible: all you need to apply the serious game is the 3 tablets and 3 stools for the children, on which the children can physically rotate. A digital version also makes it easier to disseminate essential information among players.

The game is a result of various insights obtained from both theory and previous field tests, which translated into the final design. In addition to the design choices linked to the goals, as described in Table 1, more specific decisions were made to create the serious escape game. The creative workshops with children inspired the chosen theme and the story, where the children unanimously chose thrilling themes for the game. However, the choice was made to translate the degree of urgency to progress through the game into a narrative, something that has added value in escape room design [58], rather than a terrifying theme such as a murder room that potentially contains repulsive images. For the girl, an archetypical figure was chosen that faces similar challenges in daily life as children with ASD [25]. In a debriefing session, children can together reflect that children sometimes feel alone in the classroom and introduce peers to the challenges some children face at school. The puzzles and their levels are a result of the 3 previous test sessions and the process of testing and reconstructing them. An overview of the puzzles can be found in Multimedia Appendix 1.

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Table 1. Goals and translations into design.

Perspective and goals	Translations into design	Legitimation
Children		
Fun and engaging	• Appearance • Challenging puzzles • Exploring as game mechanic • Escape room structure for engagement	• Creative workshop with kids (iteration 1) • Test sessions prototypes • Discovery as game esthetic [75] • Conceptual escape room structure as an engaging mechanism [58]
Connection with peers	• Activity-based game • Narrative transportation • Narrative to give input for debrief • Equal roles during play	• Theory on activity based [30] • Narrative transportation [76] • An archetypical figure was chosen that faces similar challenges [25] • Equality as a mechanism in forming relationships and friendships [27], thoroughly tested in previous test sessions
Theme and narrative	• Thrilling atmosphere • Storyline for the escape room	• Creative workshop with kids (iteration 1) • Narrative as an essential ingredient for escape rooms [58]
Therapeutic		
Turn-taking	• Necessary information to fulfill game divided over tablets	• Distribution divided among players, as a result of previous test sessions and theory on information distribution [44]
Cooperation and equality	• Integration cooperative mini games • Roles different per puzzle	• Cooperative nature of escape rooms [54-58] • Results from previous test sessions
Joint attention	• Necessity to coordinate attention between game and puzzles and the other players	• Choice for medium based on the results from previous test sessions and theory on information distribution [44]
Vocalization	• Distribution and presentation of information puzzles lead to the necessity to verbalize information until the communicative goal is met	• Distribution divided among players and choice for medium, which facilitates this mechanism, as a result of previous test sessions and theory on information distribution [44]

Results: Game Test

Before the test session, the children received a short briefing explaining the game's controls and stating that cooperation and communication would be essential for the successful completion of the game. At the beginning of the session, the children expressed their appreciation of the game's graphics. The children's experience with games ensured that the children quickly learned how to operate the game.

While playing, the players mostly spent the first few minutes exploring their rooms. Sometimes, a player had already started on a first puzzle but did not yet get in touch with his or her fellow players, because he or she was still busy looking around in the room. All groups entered the flow of the game after about 3 minutes, and from that moment on, they started communicating. The game requires the players to continually switch between looking at the tablet and communicating and looking at each other face-to-face. In practice, this mechanism did not hinder face-to-face contact very much. Children had a moment of dialog at each puzzle during play sessions, where they lowered the tablet to take a moment to discuss and exchange information. Generally speaking, the input on collaboration seemed equal throughout the sessions; each player was more in control at certain times in the game because of the composition of the puzzles and the distribution of information.

After about two-thirds of the game, the game contains a puzzle in which all players have to search for a part of a numerical code with an infrared flashlight. As this puzzle's flow is deliberately different (the only puzzle where 3 players have to look for a clue and exchange the object), players often got stuck here for some time. One group could not get past this puzzle by itself; the other groups needed a small hint to get back on track. This puzzle put the players' patience and skill of turn-taking to the test. At the end of the game, the players celebrated their success together. Play sessions lasted an average of 40 minutes.

On the basis of the test, the puzzles seemed neither too easy nor too difficult, given that the children only needed one small hint to get back on track during the game. The children were focused and immersed during the game and knew based on the feedback—every puzzle was a step closer to the end of the game—that there was progress in the game. The goals of the activity were clear given that the children started immediately and asked no questions during the game. After the game, when the facilitator told how long it had taken the children, children

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were often surprised that the time had gone so quickly, indicating that they had lost some of their sense of time during play. According to one of the children: “I didn’t realize we had been playing for so long.”

During the game, the children were observed using the Playground Observations checklist. During the game session, the researcher scored 10 items as either present or absent. The researcher did not know which children were diagnosed with ASD during the observation. Afterward, a teaching assistant who was always present during the test checked the observation scores. The results are presented in Tables 2 to 4. The results show no significant differences in play behavior between children diagnosed with ASD and their peers who attended special primary education for different needs. Most of these behaviors were observed. After the game, the children rated their cooperation level and gave a rating to the game. Only one child rated the level of cooperation relatively low, with a 7 out of 10. All children gave a positive rating for the game.

Table 2. Participants’ game test results.

Item	Participant											
	1	2	3	4	5	6	7	8	9	10	11	12
Gender	M[a]	F[b]	F	M	M	F	M	F	M	M	M	M
Diagnosed with ASD[c]	No	Yes	No	Yes	No	No	Yes	No	No	No	Yes	Yes

[a]M: male.

[b]F: female.

[c]ASD: autism spectrum disorder.

Table 3. Results: Playground Observations checklist.

Item	Participant											
	1	2	3	4	5	6	7	8	9	10	11	12
Engages in social play with peers	1[a]	1	1	0[b]	1	1	1	1	1	1	1	1
Is not socially isolated from peers	1	1	1	0	1	1	1	1	1	1	0	1
Respects boundaries and personal space	0	1	1	1	1	1	1	1	1	1	1	1
Does not exhibit socially inappropriate behavior	1	1	1	1	1	1	1	1	1	1	1	0
Follows rules of a game	1	1	1	1	1	1	1	1	1	1	1	1
Responds to winning or losing	1	1	1	1	1	1	1	1	1	1	1	1
Initiates communication with peers	1	1	1	1	1	1	1	1	1	1	1	1
Sustains a conversation with a peer	1	1	1	1	1	1	1	1	1	1	1	1
Does not exhibit gross motor incoordination	1	1	1	1	1	1	1	1	1	1	1	1
Uses playground equipment functionally	1	1	1	1	1	1	1	1	1	1	1	1

[a]1: present.

[b]0: absent.

Table 4. Participants’ ratings.

Item	Participant											
	1	2	3	4	5	6	7	8	9	10	11	12
Score (out of 10)	8	10	9	8	10	10	10	10	10	10	9	9
Rating level of cooperation (1-10)	9	8	8	8	7.5	8.5	10	9	9.5	8	7	9
Rating game	9.5	9	9	9	9	9	10	10	9.5	9	9.5	9

Expert Evaluation

For the expert evaluation, a session was organized at a central location for all participating experts who normally work from different locations. During the session with the experts, first, the game was played. The experts had more trouble with the controls; however, once they had managed to control them, they were at least as enthusiastic and immersed as the children. The experts did not go through the whole game because of limited time but could get a clear picture of the game.

Experts indicated that the game could have added value to their work because it gives them an immediate impression of communication between children. They also see many possibilities in manipulating the puzzles, for example, to test

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patience or build up frustration in a controlled way and to reflect on this with the children subsequently. All experts indicated that the game was particularly suitable for children who already knew each other to some degree, such as children from the same class.

The experts recognized the different social skills that are usually embedded in social skill training:

> *Actually, there are many skills and sub-skills in the game, which is normally dealt with in social skills training. But they are triggered more naturally, as we saw for ourselves when we were playing.*

Upon further questioning, it appeared that the experts were referring to turn-taking, verbalizing specific images on the screen to the other players, and switching between playing and talking. Furthermore, the experts mentioned that each child plays an essential role in the game, as they take turns with a vital piece of information. However, some social skills trainers indicate that specific skills must already have been trained:

> *I doubt if you can use it directly, it does require a certain basis.*

At the same time, they see merit in trying the tool at several locations:

> *...at home with a brother and a parent, for example. You may be able to observe other patterns that influence communication.*

All experts indicated that they wanted to use the game in their practice. Experts from child psychiatric institutions would like to use the game in the final phase of group therapy so that children can put all the social skills they have learned into practice. Experts from special primary schools would like to use the game more freely and see potential in the game to develop group dynamics at the beginning of the school year. They indicate that developing the skills included in the game might add value to all children in the class. Effective cooperation, dividing attention well, and waiting for turns can increase the classroom's synergy. They would also preferably use the serious game for a more extended period and with multiple levels to prolong the experience and formulate goals with the children in a debrief and follow-up about what they can do differently next time. Special primary school experts also see a lot of potential in a good and entertaining storyline. The story remains alive between the sessions: "Children of this age are sensitive to stories, especially when certain things in the story have yet to be unravelled."

Discussion

Principal Findings

In this study, we designed AScapeD, a serious game to facilitate social interaction and communication between children with ASD and their peers. AScapeD contains various elements of existing knowledge and practical insights resulting from an iterative design research process. AScapeD was deliberately designed to provide a useful activity-based experience for players. This might be an appropriate way for the target group to directly execute social skills in a safe context. The serious game is designed to be played with children with and without ASD, as this can contribute to socialization [48], can trigger peer support [77], and might increase the likelihood of transfer [45] by allowing the children to play directly in the target context.

The game has been developed and tested in small steps to ensure that it offers an immersive and meaningful experience. There was a focus on achieving a fun and challenging experience during these steps by finding the puzzles' appropriate level of challenge for children aged 10-12 years. There was also a focus on narrative transportation [76] to involve the players over a more extended period. An escape room's conceptual structure contributes, even in digital form, to the natural emergence of communication and equal cooperation among children. The iterative process has contributed to translating the therapeutic goals into the game in a constructive way. It was a challenge to construct a game in which communication was necessary. Players had to draw on their ability to take turns, and everybody had to have an equal role throughout the game. Everyone was in the lead for approximately the same amount of time. By using 3 rapidly constructed prototypes, each of which took less than 2 days to complete, it was possible to quickly learn which translations from goals to game mechanics were effective.

On the basis of the first results, AScapeD appears to be a promising serious gaming tool to successfully trigger social interaction and connection in a playful way between children with ASD and their peers. While playing, children with ASD participate actively and equally. During play, the play behaviors of children with and without ASD did not differ significantly. Experts recognized the skills of turn-taking, vocalization, joint attention, and the necessity for cooperation in the game. The serious game appears to be feasible to pursue the formulated goals; however, according to the experts, the children already need to be at a certain base level to apply those skills. Further research should focus on what base level is required. For effectiveness, no conclusions can be drawn yet based on the observations and the applied scale.

Research Process

AScapeD results from an iterative design process structured around the DRF [67,68]. The DRF gives direction within a design process on a more transversal level, where constructing and improving prototypes in an iterative way is a central guiding theme, which was also a leading principle in this study. The DRF provides focus and direction on the central design process; however, other resources are necessary to address specific audience characteristics and mechanisms to pursue specific goals. In this study, we could quickly learn from prototypes to find a fitting and constructive translation of predefined goals into the serious game. In addition, it has been of added value to actively involve the children in the entire process and incorporate their goals and wishes in the serious game. By approaching the serious game as a boundary object throughout the entire design process, trying to address the local needs of different stakeholders, there was a constant focus on creating an inclusive design.

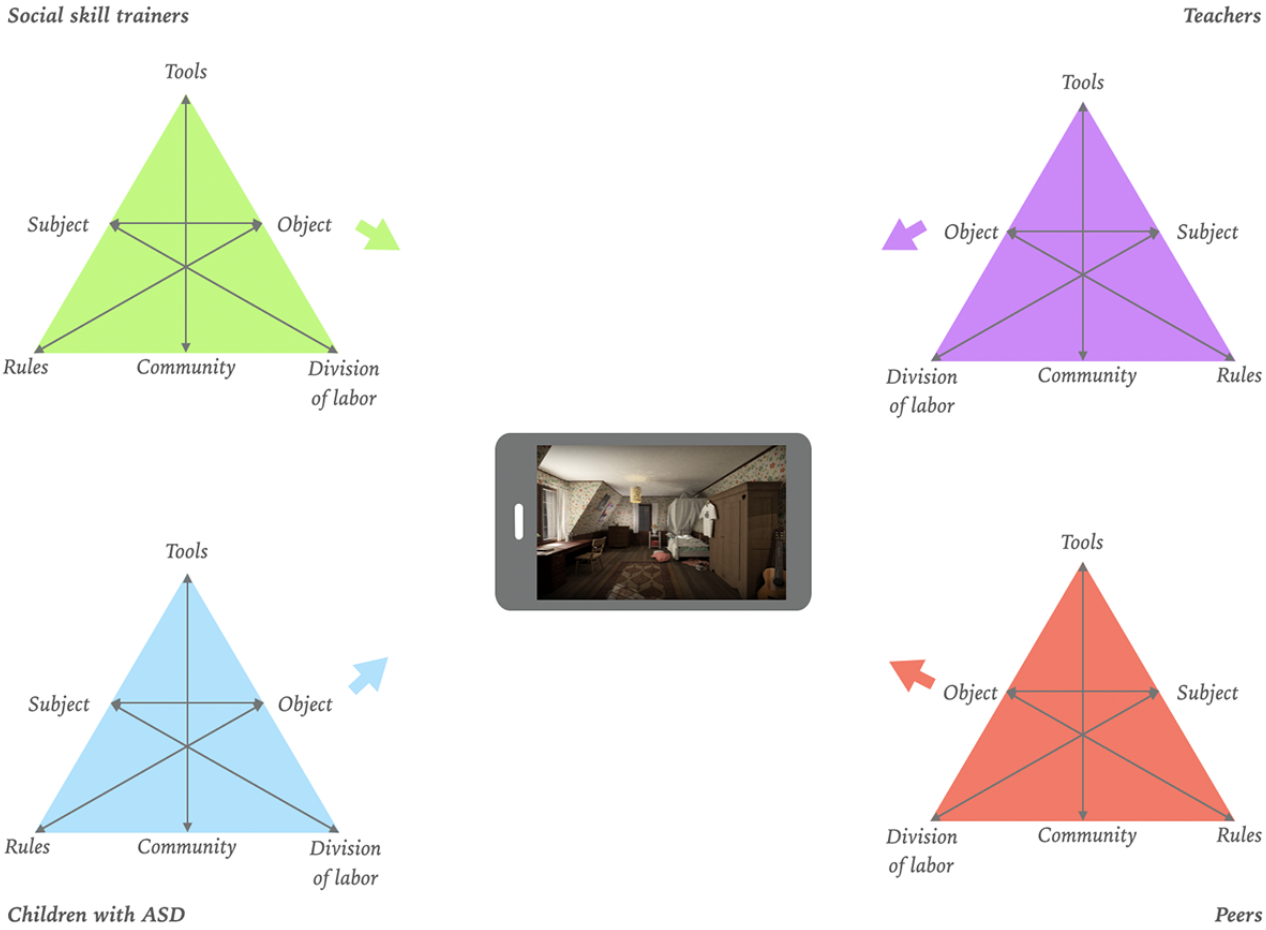
Involving children with a particular vulnerability in the research process is always a challenge. Nevertheless, in human-computer

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interaction design, it is usual to actively involve end users in a design process. Inspired by the inclusive design approach of Malinverni et al [44], we have followed this in this study by enabling children to trigger their strengths and interests and letting them play the prototypes of the serious game and let them respond to it and let them give input on specific design choices. This made it easy for children to get quickly involved in the process and made the input and feedback questions on the different prototypes very tangible.

As a result of approaching the serious game as a boundary object, the process has not led to a new tool for a specific activity system. The applied process has led to a mediating tool that contributes to different involved activity systems objects without attempting to achieve consensus between them (Figure 12). AScapeD adapts the various stakeholders' local needs and constraints and obtains a different meaning from the various activity systems. For children with ASD, a serious game is a tool that contributes to their goal of better connecting with peers. For social skills trainers, it is a tool that allows them to see how children with ASD put social skills into practice. For special primary school teachers, it is a tool that can be of added value for the development of group dynamics. The skills included can be beneficial for each child. Turn-taking, joint attention, and cooperative skills can be beneficial for each child and the group dynamics in a classroom, even if there is no developmental issue such as with children with ASD. In conclusion, for peers of children with ASD, it is a tool to have a fun experience and establish relations with peers.

Figure 12. AScapeD as a boundary object. ASD: autism spectrum disorder.



Guidelines for Future Work

From this study, we identified 5 important insights that could be useful as guidelines for future work. The following suggestions emerged from this study:

1. An iterative design approach helps to constructively translate different goals into a game. Prototyping and an iterative approach are common in game design [78-80]. In this study, this approach helped us to find the right translations from goals to game mechanics. By constructing and testing rapidly built prototypes, we obtained feedback on how constructively the predefined objectives were translated into game mechanics and how and whether the children experienced the game as a fun experience.
2. Approaching the serious game from the beginning as a boundary object [65] is helpful in addressing and adapting the local needs and constraints of different stakeholders. This perspective eventually resulted in an inclusive design. Considering the game as a boundary object has led to a continuous focus on different user needs.
3. To promote collaborative behavior, it is advisable to distribute the necessary resources, as we found out in testing different prototypes. This insight is in line with advice from previous research that included cooperative mechanisms in a game for children with ASD [44].

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4. An escape room's conceptual structure is useful for enacting communication and collaboration in a digital environment. The learning potential of escape rooms has been increasingly acknowledged in the literature [54-58]. The findings of this study indicate that the conceptual structure is also applicable to a digital environment.
5. Involving children and experts is an added value when developing a game. Inspired by the inclusive design approach of Malinverni et al [44], we gave both groups a specific role in the process. Children have provided more input on specific playful experiences and experts on therapeutic goals. In this study, this approach ensured a structured and purposeful process.

This study's inclusive approach offers a specific perspective for shaping innovation in health, mainly when innovation affects multiple activity systems. Many frameworks on implementation in health have been developed within disciplines [81]. These frameworks are, therefore, very suitable for innovation within an activity system to improve its tools. Innovation in more complex contexts involving multiple stakeholders often leads to high failure rates or a lack of impact [82]. The boundary object perspective focuses on bridging the gap between different goals among stakeholders.

Limitations

For the development of the serious game, different groups of participants participated in the study. The serious game seems promising based on the first results. However, further research is necessary to investigate whether the game is applicable in practice and whether the serious game is of added value in the longer term. On the basis of this study, the game seems suitable for high-functioning children with ASD, given that they could actively participate in the game, had an active role in solving the puzzles, and could actively communicate and collaborate during the game. The puzzles' level is tailored to children who have the IQ to follow a regular school curriculum. Scalability is, therefore, more likely to occur toward application in other contexts, where the experts call the application in a home setting and schoolteachers, for example, the application in different classes to strengthen group dynamics, rather than toward application to other target groups with, for example, children with a different diagnosis of autism or a lower IQ.

More long-term research with the serious game will have to show whether the serious game can fulfill its potential in the longer term. In a follow-up study focusing on effect rather than feasibility, the correct background variables need to be mapped out more closely. In addition, the application of a measuring instrument requires more consideration.

Conclusions

This paper presented the iterative design process of AScapeD, a serious game based on the concepts of an escape room. AScapeD triggers social interaction and connection in a playful way between children with ASD and their peers. An escape room's conceptual structure contributes to the natural emergence of communication and cooperation between children within a fun and engaging activity. AScapeD results from an iterative design process, where many insights were gained by learning from the application of rapidly constructed prototypes in practice. Applying prototypes contributed to finding a constructive translation of children's goals and therapeutic goals into the serious game. Children were actively involved in the study by participating in playful test sessions that triggered their strengths and interests by letting them play the serious game prototypes and allow them to respond to it. By approaching the serious game as a boundary object throughout the entire design process, attempting to address the local needs of different stakeholders, there was a constant focus on creating an inclusive design.

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Conflicts of Interest

None declared.

Multimedia Appendix 1
Overview of puzzles.
[PDF File (Adobe PDF File), 105 KB - games_v9i1e19765_app1.pdf]

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Abbreviations

AR: augmented reality
ASD: autism spectrum disorder
DRF: Design Research Framework

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Original Paper

Game Experience and Learning Effects of a Scoring-Based Mechanic for Logistical Aspects of Pediatric Emergency Medicine: Development and Feasibility Study

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Abstract

Background: Using serious games for learning in operations management is well established. However, especially for logistics skills in health care operations, there is little work on the design of game mechanics for learning engagement and the achievement of the desired learning goals.

Objective: This contribution presents a serious game design representing patient flow characteristics, systemic resource configurations, and the roles of the players based on a real Swedish emergency ward. The game was tested in a set of game-based learning practices in the modalities of a physical board game and an online multiplayer serious game that implemented the same game structure.

Methods: First, survey scores were collected using the Game Experience Questionnaire Core and Social Presence Modules to evaluate the experience and acceptance of the proposed design to gamify real processes in emergency care. Second, lag sequential analysis was applied to analyze the impact of the game mechanics on learning behavior transitions. Lastly, regression analysis was used to understand whether learning engagement attributes could potentially serve as significant predicting variables for logistical performance in a simulated learning environment.

Results: A total of 36 students from courses in engineering and management at KTH Royal Institute of Technology participated in both game-based learning practices during the autumn and spring semesters of 2019 and 2020. For the Core Module, significant differences were found for the scores for negative affect and tension compared with the rest of the module. For the Social Presence Module, significant differences were found in the scores for the psychological involvement – negative feelings dimension compared with the rest of the module. During the process of content generation, the participant had access to circulating management resources and could edit profiles. The standard regression analysis output yielded a ΔR^2 of 0.796 ($F1_{4,31}$=2725.49, P<.001) for the board version and 0.702 ($F2_{4,31}$=2635.31, P<.001) for the multiplayer online version after the learning engagement attributes.

Conclusions: The high scores of positive affect and immersion compared to the low scores of negative feelings demonstrated the motivating and cognitive involvement impact of the game. The proposed game mechanics have visible effects on significant correlation parameters between the majority of scoring features and changes in learning engagement attributes. Therefore, we conclude that for enhancing learning in logistical aspects of health care, serious games that are steered by well-designed scoring mechanisms can be used.

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KEYWORDS

serious game; emergency department; experience; learning engagement; learning behavior transition; logistical performance

Introduction

Emergency departments (EDs) are responders in the immediate aftermath of incidents and catastrophic situations and the foremost part of the health care system that delivers care around the clock. EDs are faced with the challenge to create a sustainable working environment despite rapidly shifting demands and preconditions for work [1]. Resilient operations are often associated with well-performing dynamic resource management and adaptive coordination to facilitate sustainable, safe work practices.

The ability to manage resources, especially when human resources are key in health care organizations, is a nontechnical skill (NTS) that requires decision making, coordination, and leadership. NTSs are defined as cognitive, social, and personal skills related to organizational robustness and resilience in management [2]. Coordination, decision making, and situational awareness are cornerstone NTSs in, amongst others, air transport [3], emergency medical services provision [4], anesthetist training [5], and nursing situations [6] in the request of maximum levels of operational safety and quality under conditions of stress and disruption. Practices such as staffing strategies and controlling, rostering, and capacity building in human resource management are important organizational strategies for creating preconditions for resilient practices for the operators who encounter the most problems [7].

Technology-enhanced learning, as a broad category of applying technology in medical and health service training situations, can be used to teach NTSs related to resource management. There are proven benefits of using a learning environment in which the learners play an active role and rely on modeling real systems, experiential learning, debriefing, evaluating play, and systematic analysis [8]. Such learning environments may be simulations and games that are used to train individuals and teams until they are technically proficient in the skills needed for a collective, reliable, high-performance working system [9,10]. The usage of serious games for educational purposes has a long history within military and engineering education [11,12]. Within medical and health care education, serious games are used for procedural training in surgery [13], anesthesia [14], and obstetrical clinical practice [15] and to enable managers to improve teamwork coordination [16], communications [17], and decision making [18,19]. A good overview of how games, specifically simulation-based games, are used for medical education can be found in Wang et al [10].

A longstanding challenge is giving the players feedback while they play in such a way that supports the learning process, specifically if the topic has a complex nature. The common method is to have experienced facilitators observe the gameplay (ie, external feedback), and often learning takes place during the debriefing session. Inbuilt mechanics like points and, in some cases, also badges and leaderboards are the most commonly used game mechanics [20] but are often disconnected from the learning experience. A different mechanic is used in math games for kids, where there is a simple right and wrong answer and the mechanics put in place are corrective and encourage retries. However, to strengthen the learning in more complex environments, stealth assessment has been more and more embedded into serious games. Progress in the field of serious games necessitates that we evaluate how game mechanics can impact learning engagement. Learning performance improvements can be expected to be the achievement goals of game-based training activities after the players have become situationally motivated through gamified processes. Recently, researchers have advanced this field from pure learning to performance-forecasting studies by taking advantage of learning analytics methods [21-23], learning benefits diagnoses, and analytical modeling based on learning behavior trajectories. The pursuit of a challenging situation and willingness to learn from the consequences of decision making are the prevalent motivation drivers in virtual environments [24]. For a contextually appropriate training and educational game design, motivational and flow experience theories provide excellent guidelines for mapping psychological needs and gaming mechanics selections [25,26].

Although recent health care simulations have been applied to identifying learners' gameplay processes [27]; understanding their knowledge acquisition process, motivation, or behavior [28]; and assessing their learning performance based on a virtual reality representation of medical complexities [29], there is a knowledge gap regarding how logistical aspects of health care operations can be gamified to encourage positive changes in learning engagement when training and practicing nontechnical decision-making skills related to essential logistical features [30]. Whether scoring-based game mechanics based on the logistical features of the health care system can be efficiently used as attributes of learning engagement has yet to be explored. Serious game analytics may open opportunities for a better understanding of engagement in game-based learning environments [31]. In addition, there are no human-computer simulation practices in recently published gaming articles on the delivery of care in health care organizational settings nor are there scoring systems to gamify the logistics of care within a pediatric ED [32], even though the scoring system is the most frequently used gamification element in comparison with badges, leaderboards, avatars, levels, and rewards.

Based on these observations, the following research question is asked in this study: Does a scoring-based game mechanic closely connected to the patient flow and logistical processes of an emergency department motivate players to interact with artifacts in a simulated emergency care unit?

The ability to motivationally interact with learning artifacts is recognized as engagement in a learning process [33]. The conceptual link between learning and engagement refers to the adoption of cognitive strategies based on self-regulation of

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performance in learning processes, with both theoretical models converging on the belief that more efficient and higher-quality engagement is available when students use the necessary cognitive knowledge and skills. The learning engagement attributes should accentuate the order of magnitude at which the players are influenced by gamification features. It is also interesting to explore whether the attributes themselves can explain logistical performance in a health care production serious game. Since the object of this study is to recognize how students experienced the use of the serious game and to explore the extent to which the proposed scoring-based mechanic influences learning engagement, the overall research question in our study is operationalized in the following research subquestions: (1) In what ways does the use of the logistical serious game influence students' experience? (2) How, if at all, does the use of the scoring-based mechanic enrich learning engagements?

Based on previous studies' usage of the number of initiated tasks and finished tasks as learning engagement attributes [31], we addressed relationships between logistical performance and the following traits, for which a regression model was performed:

- Is the number of initiated activities for resource content editions positively related to logistical performance in the serious game?
- Is the number of initiated activities for patient profile updates and investigations positively related to logistical performance in the serious game?
- Is the number of invitations for cooperation positively related to logistical performance in the serious game?
- Is the number of finished activities positively related to logistical performance in the serious game?

To answer these research questions, this study designed a logistical outcome-based scoring system and evaluated its effectiveness and acceptance in a fully pledged game-based training and learning exercise.

Methods

Game Design

This section presents the design of and scoring mechanism in the game.

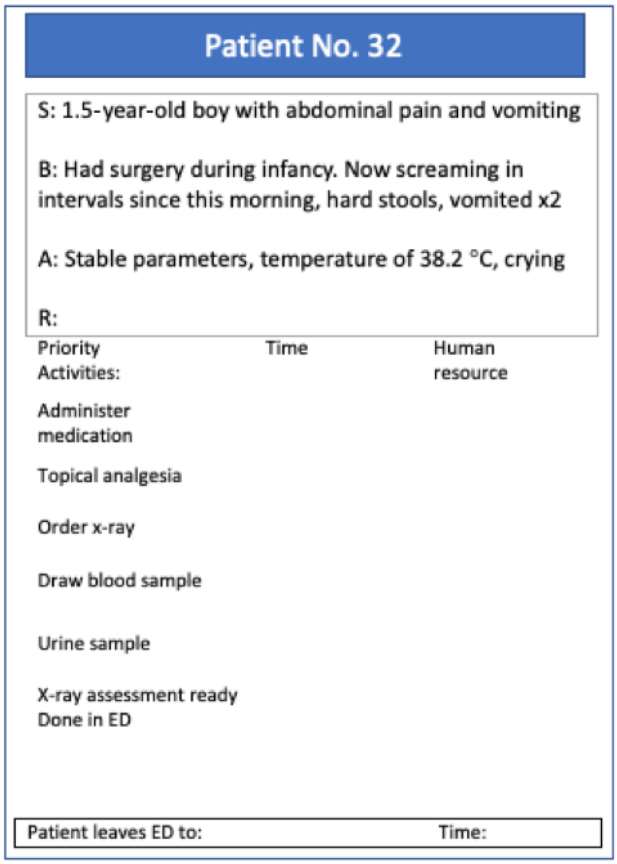
Game Scenario Description and Narrative

The ED receives a predefined number of incoming patients, who are triaged each round based on actual patient flow data from a large pediatric ED. Decisions need to be made by the triage nurse regarding whether the patient is referred or stays in the ED.

The serious game is designed to facilitate the practice of core NTSs in a health care production environment. The patients are represented using profiles, as illustrated in Figure 1. There are 90 such unique profiles. Patients are prioritized before being diagnosed or treated by doctors and nurses who work at the modules. Each patient requires an individual resource plan from the responsible person at the appropriate module. The use of stretchers and the priority levels of patients are decided using negotiation between modules and the triage station. Urgent patients, the only level indicated on the profile, must be sent to the red module. The game encourages the organizational dynamic between individual key performance indicators and a high-performance working system at the organizational level with a better patient flow and shorter lead time.

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Figure 1. Game card representing a patient. ED: emergency department. SBAR: situation, background, assessment, recommendation.



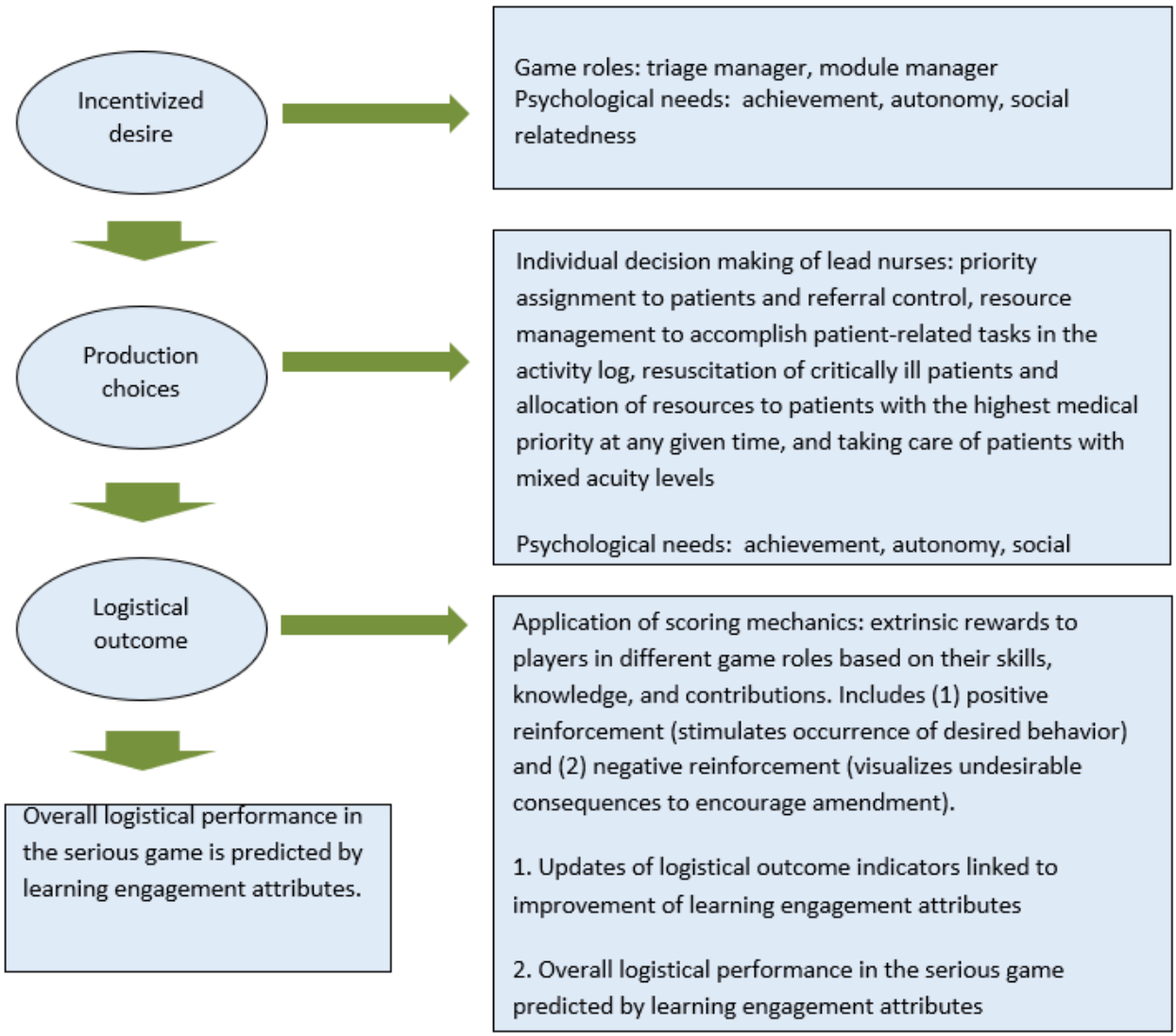
Application of Motivational Theory in Serious Gaming for Logistical Aspects

As the learning goal of the game was to practice NTSs in the dynamic resource management scenario of a pediatric ED that faces challenges related to case mix and low-acuity inflows, the design focused on encouraging participants to work toward the desired system performance and visualize less effective behavior so that it could be used for reflection and learning. Although previous studies have been based mostly on the fulfillment of players' psychological needs [34,35], the game design in this study was based on reinforcement theory as a motivational theory that is widely and successfully used for procedural training and education in health care production settings (Figure 2).

The reinforcement theory of motivation focuses on what happens to an individual when he or she takes action to enable a controlling mechanism in line with organizational goals. Both positive and negative reinforcement are integrated with all logistical outcome indicators to offer positive responses when the participant makes the desired choice related to the flow (ie, implicitly this means the throughput time and the quality of the production), leading to a plausible logistical outcome and reducing the possibility of repeating undesirable production choices. The reward system therefore rewards a decision that is in line with the mapped real processes and punishes ones with deviation, which is a typical behavioristic approach that, when applied in a game with immediate feedback, will have a motivational trigger effect. Thus, regarding the measurement of learning engagement, several proxy attributes were used to describe how active participants were in the serious game (Figure 2). First, the number of addressed tasks was measured. The players address tasks by initiating an investigation of patient profiles, allocating resources, and coordinating with other lead nurses. The activity of the player was measured based on how many tasks were initiated and in how many tasks the player was involved. Second, we measured the time spent on the task. The rationale was that this would sufficiently indicate the focus of the player in carrying out their task. Increased time performing operational tasks represents a moderate relationship with achievement. Third, we measured the number of finished tasks. This is a learner-generated metric on the number of tasks correctly answered. The measurements of concentration are useful for understanding participants' cognitive load in learning and for user behavior modeling analysis. Figure 2 describes the relationship of the 3 measures used for user engagement and motivation to the 3 types of game activities and explains which psychological needs they serve. This impacts the game flow and the cognitive workload and immersiveness the player feels while playing and triggers the training of procedural knowledge.

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Figure 2. Reinforcement theory of motivation applied to serious gaming for logistics processes in emergency medicine.



Scoring-Based Mechanic for Logistical Aspects

As described in the introduction, an important factor that supports the learning process while playing is the inbuilt feedback the player receives during gameplay. Consequently, the game mechanic needs to be meaningful for the player (ie, based on the inbuilt feedback). The player needs to understand if the decision or process execution they just performed in the game is correct. As described in the "Game Scenario Description and Narrative" section, the narrative comprises the core of the learning process and focuses on acquiring procedural knowledge. This process is triggered by events. The focus is on improving the flow and resource usage. This needs to be reflected in the feedback and scoring mechanism both to support the player in performing the task while playing and to measure if the player made the right decisions. A possibility of doing this is to use the same metrics in the game as used for measuring logistics performance, which are typically related to time, quality, and costs. A good basis for this is the level 1 metric in the supply chain operations reference model [36], which can be used for both rewarding a desired or correct decision or for penalizing a wrong execution.

The relevant indicators in each process of the gameplay used for scoring the player performance included production throughput, activity executions, resource management, and production resilience. For production throughput, a point is rewarded when a patient is discharged from the emergency department. Activity executions, based on a comparison of an individual resource plan in the gameplay and the reality, are performed for each simulated incoming patient in order to impose penalty points for any delays of production. This scoring mechanism contributes to process quality and on one side shows deviation from the expected procedure and clearly indicates if medical activities as registered in the patient log are carried out in the right modules. For resource management, penalty points are imposed for the absence of the right staff in corresponding activities. The requirements of doctors and nurses refer to the estimation from subject matter experts based on the operational practice. This is also related to process quality and is implemented in order to point out the importance of planning resources (in this case, the medical staff with the right qualifications). Production resilience is represented by the availability of doctors, as they are the core competent medical

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employee in almost all kinds of medical care. This scoring mechanism is introduced to ensure that the players pay attention to the aspects of flexibility and adaptability to react to unexpected events (eg, getting more patients than planned, a critical person getting sick, or a device not functioning). It is related to the risk appetite an organization needs to have.

These 4 different mechanisms are implemented in the different processes in the gameplay. The implementation and how it is applied in the game is shown in Table 1, which considers the production and resource characteristics of pediatric emergency medicine. Provided that the positive and negative feedback framework is psychologically beneficial for systematically effective employee performances in operational settings, as demonstrated by Losada and Heaphy [37], the optimal ratio of 6:1 for the distribution of positive and negative feedback is used for the calibration of the order of magnitude for each role in emergency medicine delivery.

Table 1. Overview of the scoring-based mechanic for corresponding logistical aspects in the pediatric emergency medicine case study.

Indicator	Scoring-based game mechanics		
	Red module responsible	Normal modules responsible	Triage place
Production throughout	+16 tokens	+4 tokens	A quarter of the tokens the receiving module earns but –1 token for every 2 rejections
Activity execution	–4 tokens for +25%; –8 tokens for +50%; –12 tokens for +75%; –16 tokens for +100%	–1 token for +25%; –2 tokens for +50%; –3 tokens for +75%; –4 tokens for +100%	N/A[a]
Resource management	–4 tokens	–1 token	–1 token
Production resilience	–4 tokens	–1 token	N/A

[a]N/A: not applicable.

Game-Based Learning Practices

The players in the pilot study evaluating the game effect were recruited from master's students participating in relevant courses from the Department of Biomedical Engineering and Health Systems. A total of 36 students were recruited for the sandbox game and web-based multiplayer serious game in 2019 and 2020, respectively. The participants received a briefing about the roles, resources, and rules of the game.

Learning Behavior Analysis Based on In-Game Data

In-game behavior data were collected. As an initial point of activating the behavior chain, the player was informed of any changes to the point system. All logistical aspects were considered. The behavior coding was then performed in accordance with Table 2. All selected behaviors shown in Table 2 are based on previous studies, with necessary adjustments according to the content of the serious game and the research questions in this study. The data were automatically exported from the multiplayer serious game application and manually judged based on tape recordings of the playing of the board game. Then, the raw data set was created by transcribing in-game behaviors into learning engagement attributes. The logistical performance dependent variable was computed as the number of tokens during a participant's entire training session.

Table 2. Participatory behavior coding guidelines.

Behavior (code)	Account
Managing resources (MR)	The participant's resource management and coordination activities for emergency medicine personnel
Editing profiles (EP)	The participant's editing of basic patient information, including titles, tags, and classifications
Inviting cooperation (IC)	The participant's efforts to share with the rest of the team for managing resources or editing profiles
Finishing tasks (FT)	The participant's confirmation of decision-making results in the simulated system

Gamification Acceptance Evaluation Based on Questionnaire

After playing, each player was asked to answer the Core and Social Presence Modules of the Game Experience Questionnaire (GEQ) validated from a previous study to obtain insights into the experience of gamification and gaming with a digital game practice and multiplayer board game [38]. The main goal of the questionnaire was to evaluate whether the game mechanics were accepted and whether the gamified processes were easy to play and understand. The dimensions were competence, sensory and imaginative immersion, flow, tension or annoyance, challenge, negative affect, and positive affect. The answers to these questions were based on a 6-point Likert scale, with 0 meaning "not at all" and 4 meaning "extremely."

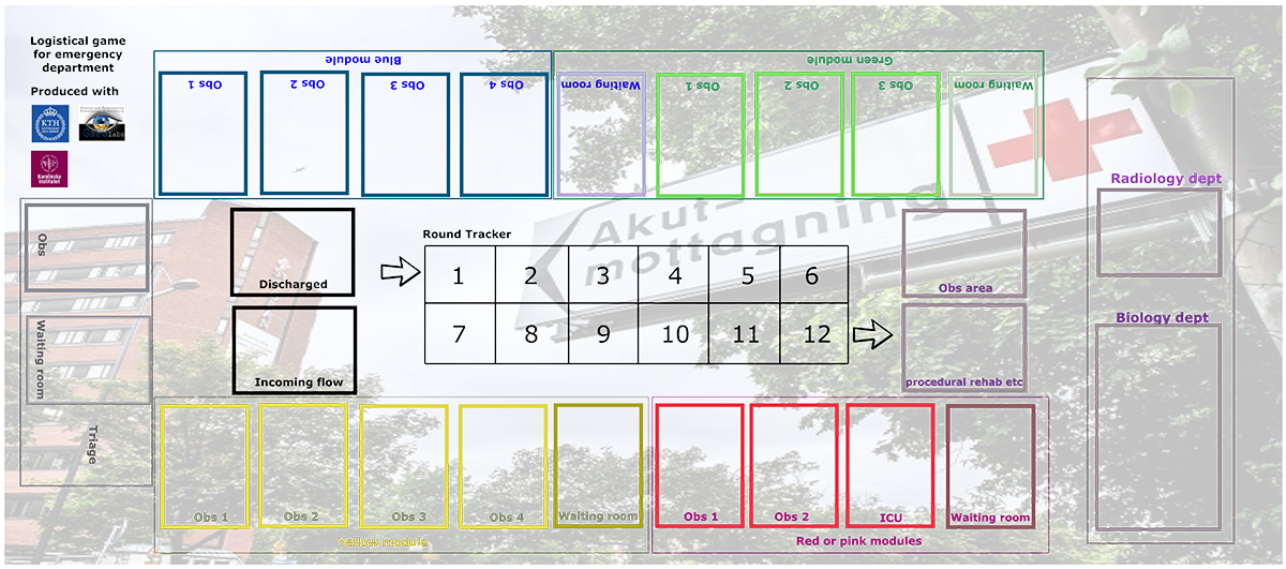
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In addition, the participants answered a questionnaire that featured 3 dimensions of social presence based on a 6-point Likert scale, with 0 meaning "not at all" and 4 meaning "extremely." These dimensions were psychological involvement – empathy, psychological involvement – negative feelings, and behavioral involvement.

First Case Study: Sandbox Game

The first case study was based on an analog sandbox game (Figure 3). The game requires participation from 5 module nurses, simulating 5 modules, and 1 individual management nurse, playing the triage place in the ED. The team under the control of the management role is composed of physicians and nurses who take care of all activities.

Figure 3. Sandbox game for simulating emergency medicine. Dept: department; obs: observation.



The ED receives a predefined number of incoming patients for triage each round based on actual patient flow data from a large pediatric ED, and decisions must be made by the triage nurse regarding whether the patient is referred elsewhere or stays at the ED.

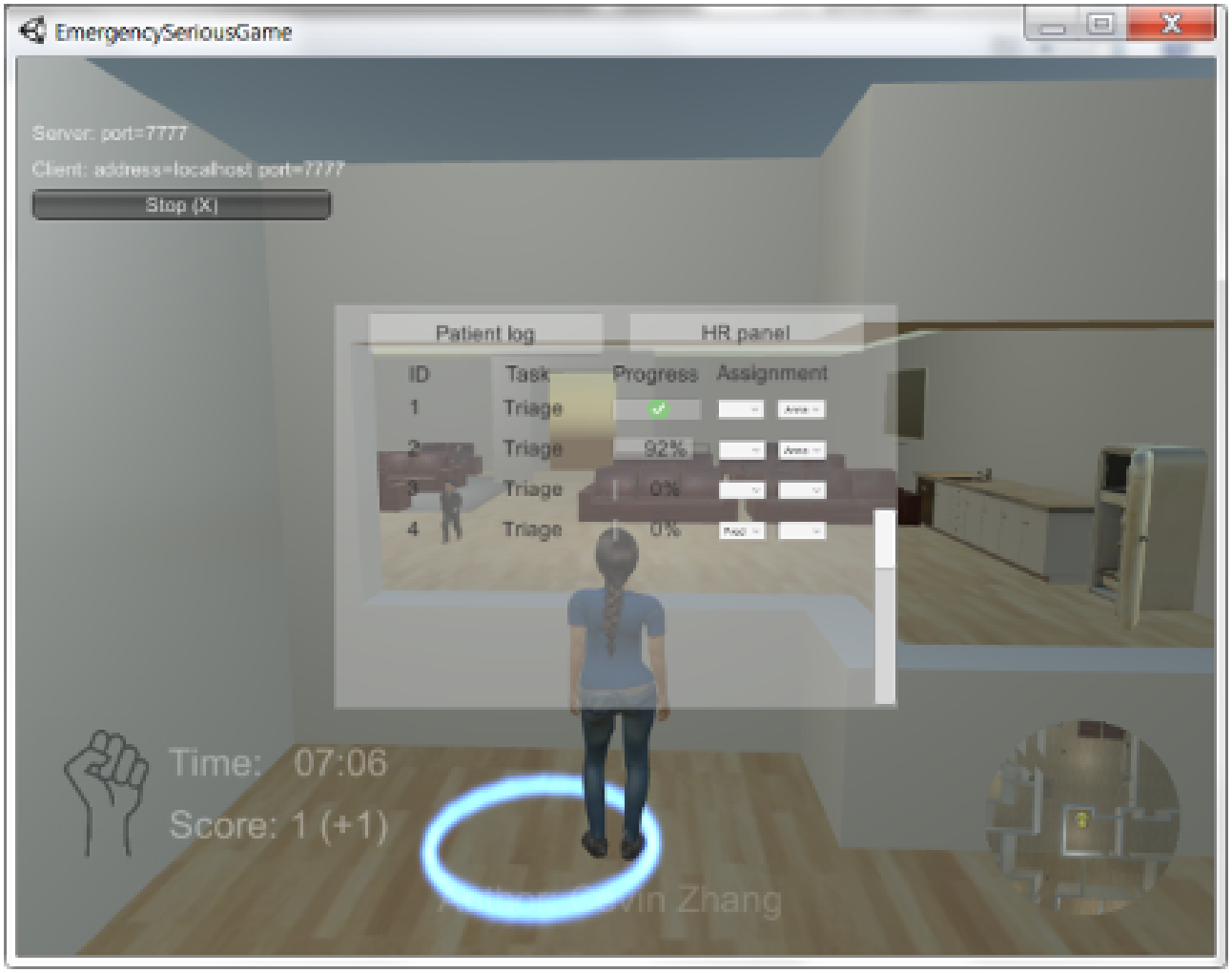
The patients who stay at the ED are prioritized and then cared for by the simulated teams of doctors and nurses who work at the workstations or modules. The session lasts 12 rounds, simulating 6 hours in real time. Each patient has a unique profile for prioritization and activities, requiring human resources that are allocated by the person responsible for the module. The observation rooms and patient prioritization are decided by the module nurses and triage nurse, with urgent patients indicated on cards sent to the red module as an exception.

Second Case Study: Multiplayer Online Serious Game

The second case study took place via teleconference, with the same participants playing a serious game programmed in Unity (Unity Technologies). An online gaming lobby was available before each session from the built-in UNet service. The players were prompted by the workstation indicators if there were tasks assigned to their specific modules. Resource management occurred through the digital protocol when the players entered the working areas (Figure 4). In addition, the players could navigate the simulated emergency department and interact with nonplayer characters, such as patients, doctors, and nurses. Unlike the sandbox game in the first case study, the multiplayer online serious game automatically calculated and presented the player's score. It is important to note that the actual game mechanics were identical between the analog and digital game.

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Figure 4. Screenshot of the Unity-based multiplayer serious game. HR: human resources.



Ethical Approval and Considerations

The study sought ethical approval from Stockholm's regional board of ethical approval, which resulted in the decision that the use and processing of any data in this study do not require ethical approval (case No. 2019-0744).

Participation in the games did not affect students' grades and great care was taken to ask for students' voluntary participation, apart from any mandatory learning activities. The examiner of the courses involved did not attend the gameplay sessions and was not informed about the results to avoid potential cross contamination.

Results

Participants

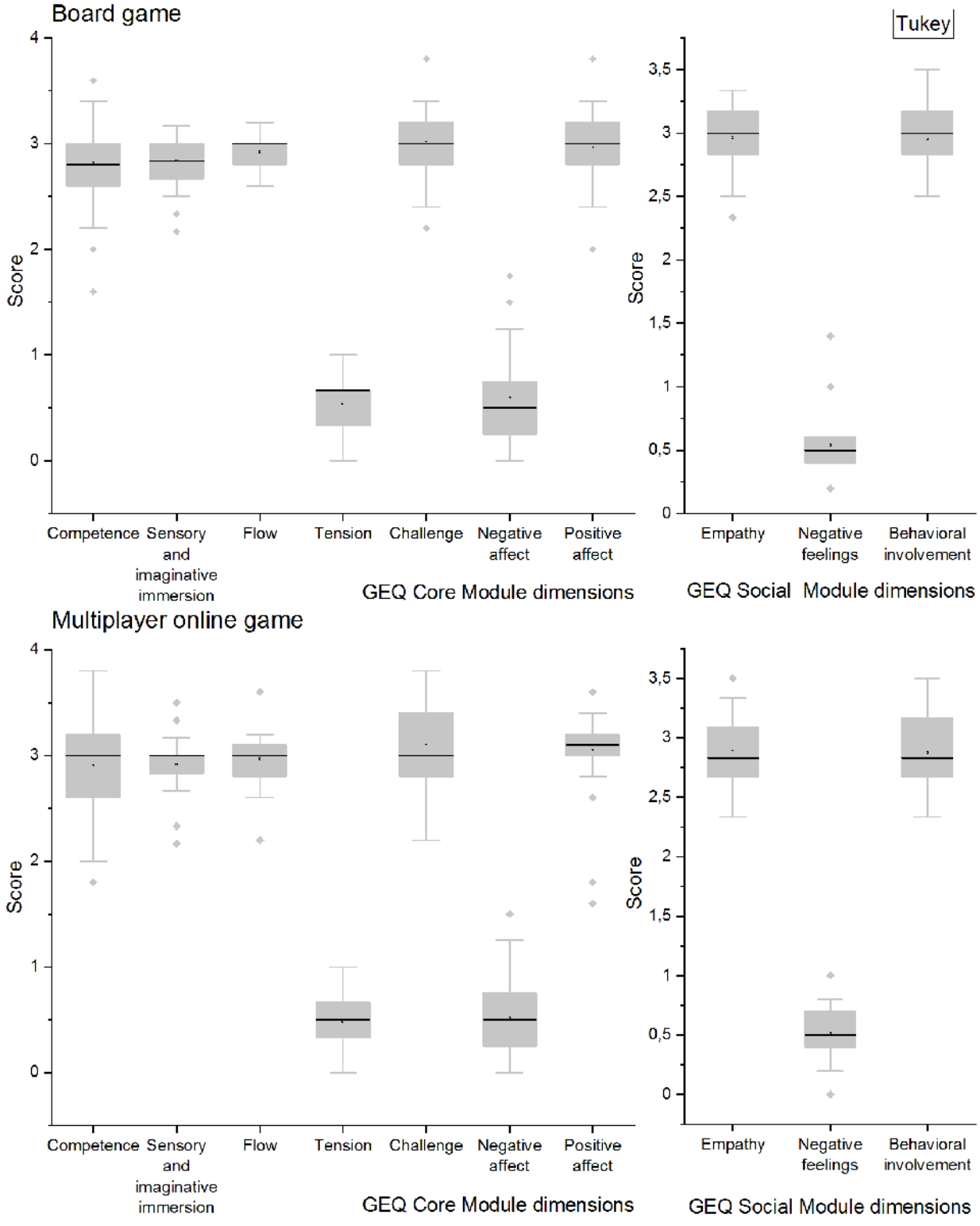
The data set of the serious game consisted of 5263 rows of raw data–containing information. The players' average age was 25.72 (SD 6.64) years. The students spent a total of 178 hours interacting with the digital environment. The students in the sample were from management and engineering backgrounds.

Player Questionnaire

In the feedback from both cases, all respondents indicated that the game realized in either modality was easy to play and understand, as Figure 5 illustrates. The Core Module items displayed high values for positive affect, challenge, and flow and low values for tension and negative affect. The assessment of the game experience revealed a significant score difference between either tension or negative affect and any of the remaining dimensions. The social presence value reported scores varying between 0.5 and 3 across 3 dimensions. Empathy and behavior involvement scored higher in the board game practice. No component-specific significant difference was reported when the modality of the game was a discriminating factor.

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Figure 5. Player questionnaire results for both versions of the game. GEQ: Game Experience Questionnaire.



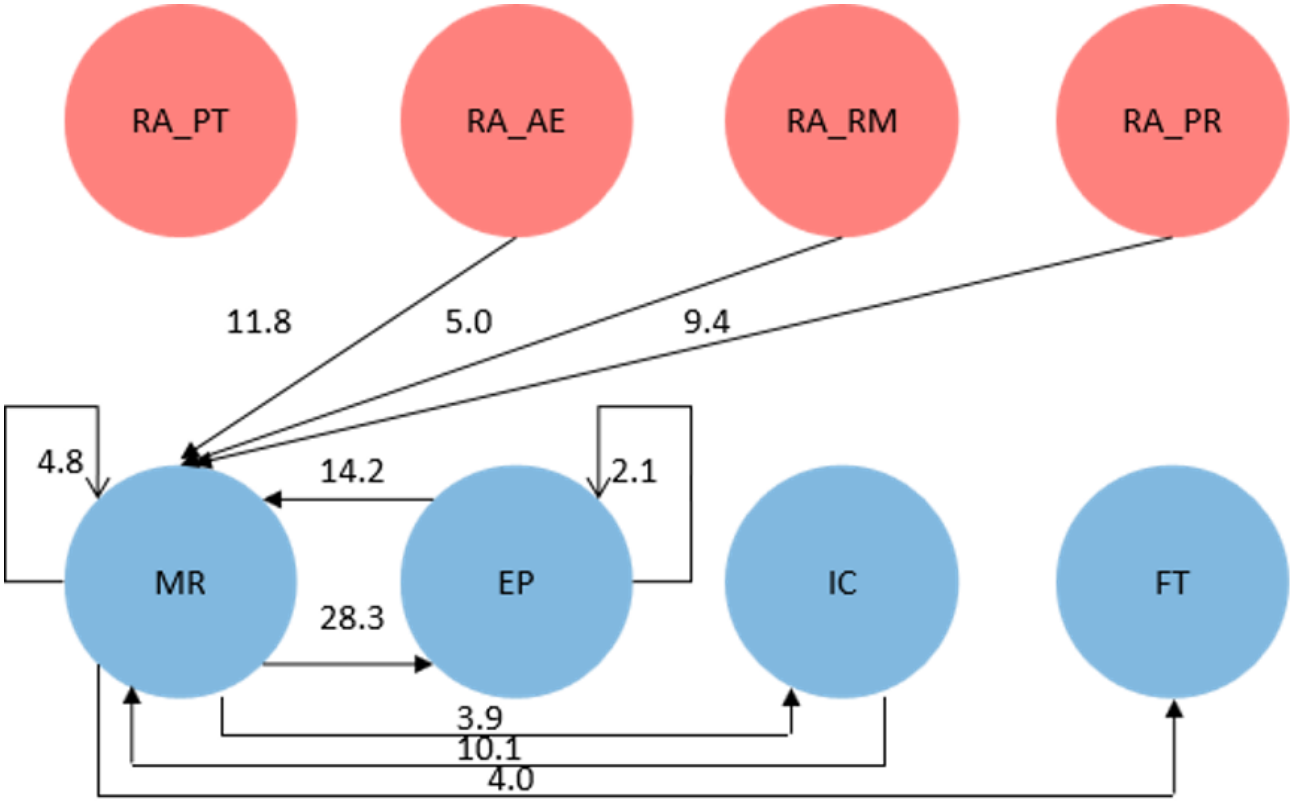
Lag Sequential Analysis of Learning Behaviors

During the process of content generation, the participant had access to circulating management resources (manage resources → manage resources: *z* score of 4.8 for the multiplayer serious game and 7.2 for the board game) and could edit profiles (edit profiles → edit profiles: *z* score of 2.1 for the multiplayer serious game only) within the time horizon, as presented in Figures 6 and 7. As long as the participant finished the resource management work, the participant probably proceeded to the work of inviting cooperation (manage resources → invite cooperation: *z* score of 3.9 for the multiplayer serious game and 2.1 for the board game) or editing profiles (manage resources → edit profiles: *z* score of 28.3 for the multiplayer serious game and 25.3 for the board game). Inviting cooperation was preliminarily followed by resource management (invite cooperation → manage resources: *z* score of 10.1 for the multiplayer serious game and 13.0 for the board game). In the

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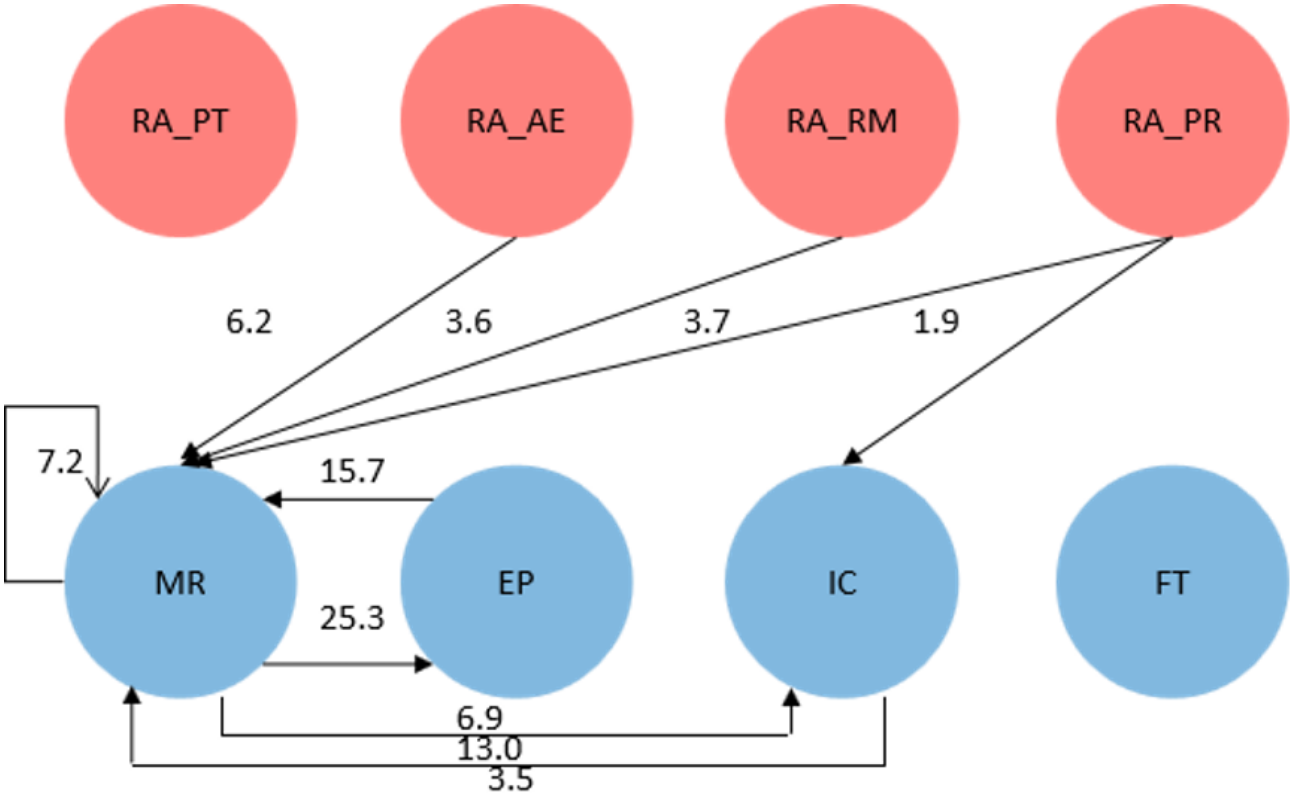
learning process, the participant acted after receiving updates from the gamification features of activity execution, resource management, and production resilience. In addition, the scoring-based game mechanics on the logistical aspect of production throughput merely activated higher-order learning behaviors. Players' synthesizing, reasoning, and evaluation were visible when they actively interacted with artifacts in this simulated environment, delivered learning behavior transitions, and were informed about logistical aspects of the pediatrics ED.

Figure 6. Behavior transition graph for the digital multiplayer serious game. AE: activity executions; EP: edit profiles; FT: finish tasks; IC: invite cooperation; MR: manage resources; PR: production resilience; PT: production throughput; RA: receiving update; RM: resource management.



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Figure 7. Behavior transition graph for the board game. AE: activity executions; EP: edit profiles; FT: finish tasks; IC: invite cooperation; MR: manage resources; PR: production resilience; PT: production throughput; RA: receiving update; RM: resource management.



Learning Engagement and Logistical Performance

The standard regression analysis for the physical board game and the multiplayer online game is presented in Tables 3 and 4, respectively. For the physical board game and the multiplayer online serious game, the output yielded a ΔR^2 of 0.796 and 0.702, respectively ($F1_{4,31}$=2725.49, *P*<.001; $F2_{4,31}$=2635.31, *P*<.001). Clearly, the number of activities initiated by a player (β=0.42, *P*<.001 for the board game; β=0.34, *P*<.001 for the online game) positively anticipated his or her logistical performance. The same was true for the number of activities finished by a player (β=0.53, *P*=.045 for the board game; β=0.37, *P*=.04 for the online game) and the effort of editing profiles (β=0.08, *P*=.01 for the board game; β=0.14, *P*<.001 for the online game). In sum, the 4 hypotheses were accepted for serious gaming for pediatric emergency medicine, confirming significant relationships between attributes of learning engagement and logistical performance in the game.

Table 3. Regression analyses predicting logistical performance based on attributes of learning engagement in the board game case study.

Variables	R^2	ΔR^2	B (SE)	β	*P* value
Logistical performance	0.796	0.796	N/A[a]	N/A	N/A
Manage resources	N/A	N/A	1.129 (0.014)	0.42	<.001
Edit profiles	N/A	N/A	0.003 (0.002)	0.08	.01
Invite cooperation	N/A	N/A	0.012 (0.006)	0.18	.02
Finish tasks	N/A	N/A	0.154 (0.089)	0.53	.045

[a]N/A: not applicable.

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Table 4. Regression analyses predicting logistical performance based on attributes of learning engagement in the multiplayer online serious game case study.

Variables	R^2	ΔR^2	B (SE)	β	*P* value
Logistical performance	0.702	0.702	N/A[a]	N/A	N/A
Manage resources	N/A	N/A	1.004 (0.009)	0.34	<.001
Edit profiles	N/A	N/A	0.003 (0.001)	0.14	<.001
Invite cooperation	N/A	N/A	0.025 (0.015)	0.31	.02
Finish tasks	N/A	N/A	0.113 (0.067)	0.37	.04

[a]N/A: not applicable.

Observations of In-Game Collaboration

Analysis of in-game comments and message broadcasting showed that the participants made more collaborative decisions in later rounds of the game (eg, they would actually handle more challenging tasks at the end of the session). This reflects the increased complexity and visibility of the effects of decisions as the number of patients in the ED increases. In early rounds, the participants were cautious about delaying the patients and attempted to organize flows as efficiently as possible. As more patients entered the ED, the key performance indicators varied among the roles. At the same time, the participants made comments and provided feedback in relation to health care management in the game (eg, the ED was easy to optimize at first, but as the session progressed, the players realized that a teamwork setup was much needed to understand the logistical aspects). This meant that the game facilitated discussions comparing it with real systems, a transition from self-regulated decision making toward collective efforts, and the achievement of learning goals.

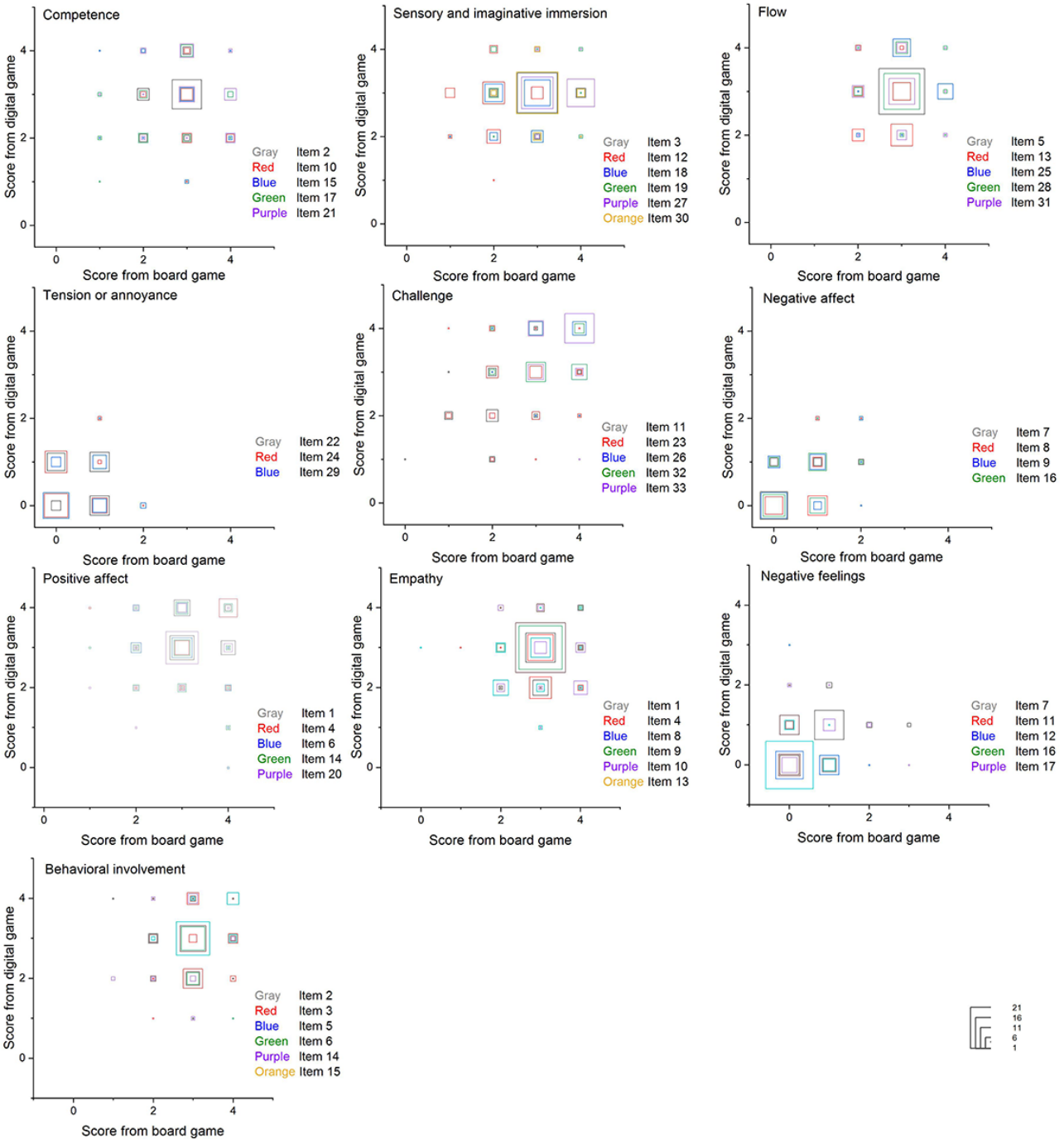
In reflecting on the game experience, the players reasoned that without combined decision-making ability, proper management of employees and management of the ED was hard. They also highlighted the managers' central roles in the coordination of work not only in monitoring but also in facilitating work and encouraging self-reflection and determination.

Experiences of the Two Game Modalities

For the challenge dimension, which was scored above 3 for both cases (Figure 8), players in both groups provided mostly positive feedback for item 33 ("I had to put a lot of effort into it") and item 32 ("I felt time pressure"). However, there were 6 players who indicated slight and moderate confirmations of item 11 ("I thought it was hard") and item 23 ("I felt pressured"). One potential explanation is that the players in both cases might have been sufficiently challenged by the large number of tasks operated in a limited time horizon in tandem with the narratives, indications, and visual communications of reality, making the game perceived as less difficult. For the negative affect dimension, which was one of the components receiving the lowest scores, players gave mostly slight and moderate confirmation for the questions. The efficacy of the game design is catching score differences tested as statistically insignificant.

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Figure 8. Questionnaire item scores correlated with gaming modalities.



Discussion

Principal Findings

This study was based on a quantitative investigation of measurable learning engagement attributes and enumerative translation into a serious game of a comprehensive variety of logistical aspects in pediatric emergency medicine. The evaluation was based on the Core and Social Presence Modules of the GEQ to evaluate the experience, feelings, and thoughts related to the serious gaming of logistical processes and management in the health care operation setting.

The results showed that the gameplay of various logistical aspects drives learning engagement attributes, and although the results were weak in strength, they were still significantly positive. Additionally, this study is based on a much larger sample of players participating in both types of gaming simulations. The acceptance and evaluation of the game design corresponded to previous studies on using both physical board simulation and web-based gaming [39], with further improvements.

Provided that both modalities can be applied in training and learning situations [40], the results are remarkable in terms of the impact of the gaming simulation modality on the game mechanics selection; the multiplayer digital version is advantageous for edutainment, whereas the board game version is more straightforward and makes the concepts easy to understand.

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This game experience study of the serious game offered meaningful feedback regarding the players' experiences, which reflects game design principles and realizations. The results indicated an overall positive evaluation for game experience, as most items had values of almost 3 or greater.

Regardless of which particular role is assumed by the players, the survey results demonstrated that the game design was accepted by the players. In addition, the behavior transition graphs from the lag sequential analysis indicated that a point-based system based on mixed positive and negative feedback encouraged the desired actions, and the negative feedback, as an essential part of the framework, was effective.

The competence and challenge components are indicators of the reliable evaluation of the learning engagement attributes that the serious game provided because they measure the subjective participation experience of the player's skill deployment to its full extent. Both components displayed high values compared with previous applications of serious games addressing health-related issues, which aimed for a higher score in competence [41,42]. The high flow and immersion values suggested that the players felt cognitively involved while playing the game. Meanwhile, the moderate-high value for positive affect and low level of negative affect and tensions indicated the motivating impact of the game. Finally, the high values for empathy and cognitive involvement and the low value for negative feeling, as well as the patterns observed regarding in-game collaboration, indicate the suitability of the game model for teamwork situations.

Our analysis shows that the number of activities addressed and the number of activities finished by a player can be reliable sources for predicting the overall logistical performance in a serious game. This is a reflection of the benefits of active learning with simulation. However, our analysis also showed that better-performing learners spent more time on each particular task. This has not been observed in previous empirical studies. Based on the fact that players revised their plans after being informed by the scoring system, this finding may be interpreted as the players becoming acquainted with situations and the goal of the game.

Anticipatory human resource management was identified as a successful strategy for achieving a sustainable working environment when the organizational resilience was confronted with patient inflow surges during the busiest hours of the busiest day, and this principle was built into the learning goals and scoring system. The findings in this study indicated that both negative and positive reinforcements were effective in encouraging behaviors in line with the learning goals of the game. Our findings show that all included learning attributes were important variables for predicting logistical performance in serious gaming and that the number of initialized tasks was the most powerful explanatory variable, in line with previous studies [31]. Additionally, via relation analysis, this study indicates that a gamification design of key logistical aspects of the health care production system can lead to learning engagement in serious gaming. The results show that the manner in which the players developed solutions and innovations to handle the increasing patient flow during the later rounds corresponded to the expectation of the game principles. The in-game scoring system supported the decision-making process in the desired way. This can be seen as a successful first step in implementing scoring mechanics to support the learning of NTSs needed in an ED. Hospital ED organizations need proactive methods to protect them from disruptive events [10].

Limitations

A methodological limitation is that the average scores for each dimension in the board game case were not significantly different from those reported in the digital game case, but this can be explained by the difference between the item scores in the same component showing a wear-off effect due to the design of the questionnaire. A more structured and systemic evaluation methodology has been proposed and validated by Carvalho et al [22]. This is a suitable framework, given that a favorable view of game-based training for health care logistics has yet to be shown. This framework will be used to measure the learning curve and the gap between gaming outcomes and observed performance outcomes to further support debriefing and evaluation.

During the game co-design process, emergency medicine shareholders noted that competition is not in line with the culture of health care staff. The emphasis is rather on prioritizing the resources to the patients who are sickest. However, the proposed scoring system aimed not to overemphasize the competing aspects but to provide information to the players on how they managed to adhere to the goals through the simulated scenarios. Also, in this first evaluation of the scoring mechanism, all 36 participants were students. To further investigate how the learning goals work for health care, the game needs to be assessed through the involvement of expert players.

Conclusions

This study shows that the game in both analog and digital forms can capture and render visible the core logistical challenges of managing an ED.

Previous studies have shown the potential of simulations as a tool for visualizing logistical aspects as well as the effects of an unbalanced use of available resources for health care managers [43].

In addition to the aim of making successful strategies visible to drive expected behaviors, our results showed that the translation of a real emergency department into a serious game and scoring system of logistical aspects also made it possible to explore the roles that communication and collaboration play in achieving the overall goal of balancing efficiency and thoroughness in the ED.

Our study shows the potential of the scoring system and the ability of the game to capture core logistical as well as safety- and quality-related aspects of managing emergency care. A simulation-based game mirroring a real work process, as presented in this study, would be of great value to teach staff tasked with patient flow management about logistical aspects and collaboration in an ED setting.

However, the game has not been tested by expert operators and thus can only demonstrate how players behaved in the context

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of prompts during gameplay rather than how they would behave based on experiences working in an ED. Therefore, in the next step, the presented results will be used to refine the built-in scoring system and make the tasks more in line with situations in an ED. This will then be tested both with students in next year's class from the same course and with ED staff.

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Conflicts of Interest

None declared.

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Abbreviations

ED: emergency department
GEQ: Game Experience Questionnaire
NTS: nontechnical skill

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Review

Tabletop Board Game Elements and Gamification Interventions for Health Behavior Change: Realist Review and Proposal of a Game Design Framework

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Abstract

Background: Games, when used as interventional tools, can influence behavior change by incentivizing, reinforcing, educating, providing feedback loops, prompting, persuading, or providing meaning, fun, and community. However, not all game elements will appeal to all consumers equally, and different elements might work for different people and in different contexts.

Objective: The aim of this study was to conduct a realist review of tabletop games targeting behavior change and to propose a framework for designing effective behavior change games.

Methods: A realist review was conducted to inform program theory in the development of tabletop games for health behavior change. The context, mechanisms used to change behavior, and outcomes of included studies were reviewed through a realist lens.

Results: Thirty-one papers met the eligibility criteria and were included in the review. Several design methods were identified that enhanced the efficacy of the games to change behavior. These included design by local teams, pilot testing, clearly defined targets of behavior change, conscious attention to all aspects of game design, including game mechanics, dynamics, aesthetics, and the elicitation of emotions. Delivery with other mediums, leveraging behavioral insights, prior training for delivery, and repeated play were also important. Some design elements that were found to reduce efficacy included limited replayability or lack of fun for immersive engagement.

Conclusions: Game designers need to consider all aspects of the context and the mechanisms to achieve the desired behavior change outcomes. Careful design thinking should include consideration of the game mechanics, dynamics, aesthetics, emotions, and contexts of the game and the players. People who know the players and the contexts well should design the games or have significant input. Testing in real-world settings is likely to lead to better outcomes. Careful selection and purposeful design of the behavior change mechanisms at play is essential. Fun and enjoyment of the player should be considered, as without engagement, there will be no desired intervention effect.

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KEYWORDS

behavior change; games; serious games; board games; behavior interventions; health interventions; health games; game design; tabletop games

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Introduction

Games as a Tool

Games—activities that one engages in for amusement or fun—have an inherent ability to elicit our interest, engagement, and motivation more than static educational material without implicit rules, objectives, and pursuits [1]. Games can leverage the underlying psychology of rewards, social norms, mastery, autonomy, and pursuit of meaning to achieve desired choices and behaviors among players [2,3]. Gamification describes the purposeful design and application of game-like elements into nongame environments. Although gamification is a broad term, the core principle is taking design elements from games or play to influence choices and behavior [4]. For a game to capture one's attention and change behavior, it must be carefully designed with a clear goal and consider numerous approaches through multiple lenses [5]. Without a thoughtful design process, gamifying something can render it ineffective or annoying, thereby potentially deterring the desired behavior or promoting undesired outcomes such as cheating or stealing, and in extreme cases, being dangerous or unethical [6,7].

Tabletop, Card, and Physical Games

In modern times, physical, card, and tabletop games may be considered unsophisticated or outdated and are often overlooked when gamification interventions are considered in favor of contemporary alternatives such as digital or video-based products. However, given that tabletop games are cheaper to produce, arguably easier to design, while promoting an inclusive and social aspect to the gaming experience, they remain a viable alternative for gamification for health behavior change interventions [8]. The universe of game design is vast. The abovementioned reasons are examples of how each aspect of game design can be considered in function toward achieving a desired behavior or goal. Despite the wide scope for application of gamification as a tool, there is minimal literature available to guide its use in the development of behavior change interventions. Overall, there is a lack of contextual understanding of game mechanics and program theories underlying gamification as a tool for behavior change contexts [9].

A Realist Perspective

Games as a tool in health care is an example of a complex intervention. This is because games are multi-faceted and dynamic, where individual agency and context can change behavior outcomes significantly. Given this, it is reasonable to presume that the same intervention would not work uniformly in different contexts [10]. Realist reviews operate within the lens of realist philosophy and allow a deeper, more nuanced understanding of intervention outcomes than standard systematic reviews. Employing the realist philosophy in the review process, we can unpack an intervention, thereby identifying what underlying mechanisms cause what outcomes, under what conditions, and in what contexts [11] providing explanation, rather than judgement, about how an intervention works [10,11]. This context-mechanism-outcome (CMO) configuration creates an explanatory model for causation. It relies on the theory of complex interventions [12], which theorizes that complex interventions have the properties of complex systems [13]. This is an innovative use of a realist review, as a game design in a behavior change setting has not been formally reviewed with a realist lens. The aim of this study was to review games and game elements designed to affect health behavior change and to propose a framework and program theory to underpin the game design for health behavior change interventions. This review focuses on the use of tabletop games as a behavior change tool in the context of health.

Methods

Framework

This realist review uses the framework for realist synthesis described by Pawson et al [14]. After a preliminary reading of the literature, the emerging central review questions generated were as follows:

1. What are effective game mechanics design elements in behavior change interventions?
2. What are the dynamic and context elements that explain outcomes of games and their use as an intervention?
3. Theory integrity and adjudication: do game element theories work as predicted and fit best?
4. Reality testing: how does the intent of gamification translate into practice?
5. Reviewing the current theory and frameworks of game design, can we propose a framework specific for game design in the behavior change context?

Formulating the Initial Intervention Theory

First, we developed a preliminary program theory following an initial exploratory review of the literature. This paper's initial program theory framework is built on the broad aspects of game principles by Robson et al [15] using categories of game mechanics, dynamics, and emotions with the addition of aesthetics from the report of Hunicke et al [16]. There are several proposed game design frameworks in the literature—18 were found in a recent systematic review [17]. We conducted additional focused searches of the literature to identify key program theories, thereby refining the search criteria considering emerging data with additional snowball searching to explore new hypotheses as they emerged [14]. The preliminary program theory is based on the hypothesis that games induce desired behavior change through play and engagement. They are a medium for incentivizing, reinforcing, educating, providing feedback loops, prompting, persuading, or providing meaning, fun, and community. However, not all game elements are appealing to all potential users and contexts. Effective game design considers the desired outcome of the intervention and targets behaviors and motivations of the individual player within the context of the choice-making environment [4]. Simply adding points, badges, and leaderboards without a purposeful design is adding gamification without clear outcomes or desired response [4,8]. The literature highlights that a number of things need to be considered such as how participants interact within the game—with each other and themselves. Game design has 4 distinct properties that govern the game experience and can be manipulated to achieve behavioral outcomes [15].

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1. Mechanics: The rules of how the game system works.
2. Dynamics: The ways in which the participants interact in response to the mechanics.
3. Aesthetics: The flavor of how the game looks, the storyline, backstory, artwork, physical appearance, or medium.
4. Emotional aspects: How it makes players feel and relate with themselves, the game, and each other.

Mechanics

Mechanics determine the rules of the universe that a game creates and will form the foundations of how participants interact. A game can be designed for cooperation or competition and the mechanics dictate how the participants interact with the game and with each other. Clearly stated objectives and the progression toward goals determine how outcomes are pursued and how feedback through gameplay can occur. Success, failure, rewards, or punishments can be used to reinforce behaviors positively or negatively through operant conditioning and intrinsic or extrinsic motivation [15,18,19].

Dynamics

Creativity and repeated play within the rules lead to outcomes between the game, players, observers, and spectators that form the game dynamics. All dynamic player behaviors can be designed purposefully to achieve behavior such as cooperation, competition, behavior loops [20], and habit formation. Even negative behaviors can provide a fun dynamics for entertaining and engaging game play [8] such as cheating, bluffing, conspiring, or even quitting [15]. Roles other than players may also form influential dynamics. Passive observers contribute to social relatedness and spectators influence the atmosphere, community, and popularity, and they impact player behavior within the game [15]. Within dynamics, one also needs to consider whether game elements will result in unwanted second-order behaviors [7], undesired or unethical outcomes, and whether there will be lasting or novelty effects on desired outcomes.

Aesthetics

The artwork, setting, physical game components, storyline, and immersive objective form an environment that can induce more engaged players and motivate continued play [5].

Emotions

Games that trigger emotional responses can be powerful behavior and learning tools but are challenging to design and more difficult to have heterogeneous control over [5,6]. Some emotions have predictable patterns and can be designed to elicit a sense of achievement, mastery, disappointment, or failure. More subtle emotional outcomes can funnel particular behaviors and can be leveraged through research in psychology and behavioral economics tools such as establishing social norms, endowment effects, scarcity, simplification, chance and probability, framing effects, reducing friction costs, network effects, salience, default states, and cognitive loads [4,5].

Final Systematic Searching for Primary Studies

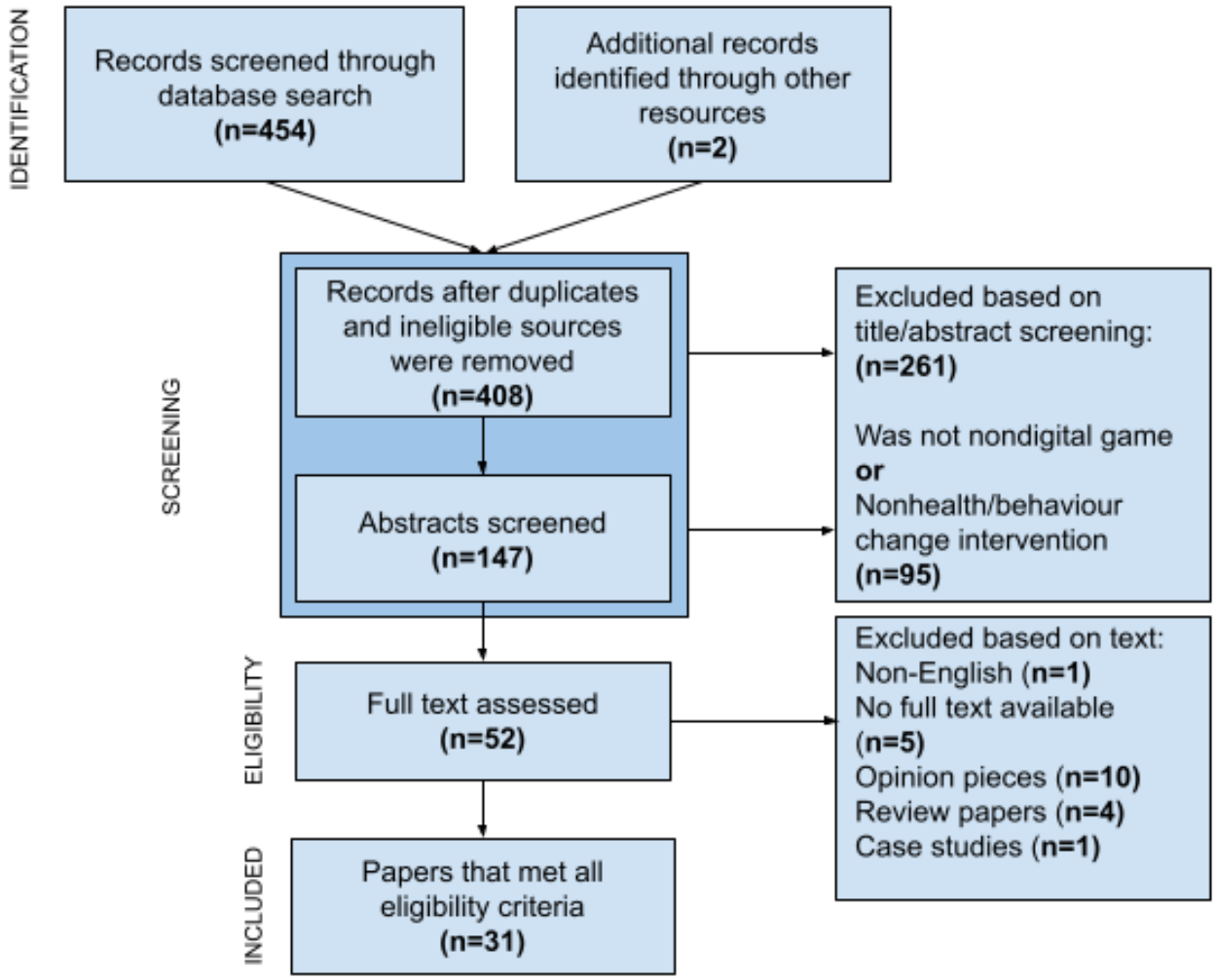
A final systematic search was performed in December 2019 (Multimedia Appendix 1). We searched 10 databases relevant to health and behavior interventions, including PubMed, Web of Science, and PsycInfo, without date restrictions. The search strategy was developed with the guidance of a medical subject librarian. The search terms included “board game,” “game,” “serious game,” “tabletop game,” “card game,” or “gamification” and “health” but excluding the terms “virtual,” “screen,” or “video,” and all publications were included in the review. We reviewed titles and abstracts to identify relevant studies. The full text of these papers was then accessed to determine if they met the inclusion or exclusion criteria and assessed for relevance and rigor to test against the initial theory [14].

Inclusion and Exclusion Criteria

Studies were included if they used a tabletop game as an intervention and measured a health or behavior change outcome. Studies were excluded if they were digital interventions, did not measure health outcomes, were not English texts, were reviews, opinion pieces, or case studies, or the full text was unavailable upon author request. Papers were initially reviewed by title, keywords, and abstracts for relevance and imported into EndNote reference manager by the first author. Full papers of articles that described behavior change interventions in the context of health were accessed and read in full to determine if they met the inclusion criteria. Papers were excluded if the full text was not available (Figure 1).

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Figure 1. Flow diagram for paper selection.



Selecting Evidence

The process of quality appraisal in a realist review is different from that of quality appraisal in a systematic review. Studies are selected based on their relevance toward building and testing theory and their rigor in terms of methodological reliability and description power. A formal methodological quality appraisal tool was not used in this study, but research was individually assessed for rigor.

Testing Relevance

Studies were expected to have adequate relevance to build the program theory. The quality of the paper was assessed to see if the study addressed the program theory under testing by contributing enough knowledge to comment on the aspects of tabletop games on health outcomes. Any paper that was not directly assessing a tabletop game intervention or not measuring a behavior change outcome was excluded at this point.

Testing Rigor

The papers were assessed by the reviewers to screen if they were free of bias and were methodologically credible enough to contribute toward the building of the overall program theories. Articles of opinion, review papers, and case studies were excluded, as were non-English texts.

Extracting Data

A theoretically derived CMO framework was populated to evaluate evidence. Data were extracted and recorded in NVivo software (QSR International) during this process. Information extracted included name of the game, country and setting, method of delivery of intervention, demographics of participants, study design, sample size, comparison group exposure, mechanism of intervention effect, behavior change outcome, and any context-dependent outcomes.

Analyzing and Synthesizing Findings

To refine the preliminary program theory, we interrogated the literature asking:

1. For *whom* did this basic program theory work and not work, and why?

2. In what *contexts* (C) will this program theory work and not work, and why?

3. What are the main *mechanisms* (M) by which we expect this program theory to work?

4. If this program theory works, what *outcomes* (O) will we see?

This formed the codes used for tabulation, indexing, and linking to the program theory in a CMO configuration for each of the

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effects and their relevance to strengthen the initial program theory.

The resulting CMO configurations were reviewed by 2 authors (DE and CB) for quality assurance during synthesis. This was achieved by identifying recurring patterns and outcomes in the data, confirming and modifying the reviewers' understanding of the data, and assessing if the CMO configurations helped inform the hypothesized theory, thereby seeking to both confirm or contradict the findings [21].

Results

Literature Review Findings

We identified 454 papers in our initial literature search. Two more papers were identified by hand searching the reference list of included papers. After the removal of duplicates and title screening, 408 records remained. Exclusions in title and abstract screening for applicability (n=261) and exclusions of nondigital games and nonhealth/behavior change interventions (n=95) were made, leaving 52 papers for full-text review. Further papers were excluded where the full text could not be accessed (n=5), or if papers were opinions (n=10), review papers (n=4), or case studies (n=1). One paper was not available in English (n=1). Papers that met all the eligibility criteria (n=31) were included for review (See Figure 1 and Table 1). A description of the included studies can be found in Table 1 and Multimedia Appendix 2. These studies were mainly conducted in Europe (n=13) and North America (n=8) with Africa (n=4), Asia (n=3), and South America (n=2) also having representation. The participants in these studies (20 papers) were mostly younger than 18 years. Several studies had interventions resulting in successful behavior change. The types of successful behavior changes observed included understanding of adolescent smoking [22,23], better nutrition in schools and young people [24-29], recognizing symptoms of delusions and psychosis [30,31], infectious disease education and understanding [32-35], prevention of alcohol abuse [36], chronic disease prevention and management [24,37-40], sexual health practices [32,33,41], and understanding of pregnancy and breastfeeding [42,43]. There was evidence to support the preliminary program theory that identified elements of game design mechanics, dynamics, and aesthetics. Additional consideration was placed onto the context of the participants and research and understanding of the behavior change mechanism components at play (see Table 1 and Table 2).

Table 1. Contextual and mechanism factors that enhance efficacy of games in behavior change.

Evidence type/factors	Game design elements described in studies
Strong evidence across many trials	• Games developed by local teams rather than designed by distant subject experts [22,27,30,31,40,41,43-45] • Games reiteratively developed through pilot testing with target users and context [22,27,29,41-43] • Clearly defined behavior-change goals targeted and reflected in game design [22-26,29-31,34,36,37,39,41-43,45-49] • Conscious attention to consider game mechanics, dynamics, and aesthetics to increase engagement and target desired behavioral changes [22-32,37,38,41,43,45,46,49] • Delivery combined with other mediums or learning modalities [27,28,32,34,35,38,40,46,47] • Games that leverage behavioral insights such as social norms, emotive engagement, operant conditioning, or intrinsic motivations [22-26,30,31,41,43]
Limited evidence from one or few trials	• Consideration to training before delivery or play [27,29,31,33,41,44,48,49] • Multiple exposures to play [23,34,36,39-41,43,45]
Possible factors worth considering in future research	Increasing time series measurement to understand behavior change extinction effects [24,31,33,37,39,42,44]

Table 2. Context and mechanisms leading to positive behavior change outcomes in a realistic game design theory.

Mechanisms	Descriptions in the studies
Aesthetics of fun and play increase engagement and information uptake	The fun and attractiveness of games leads to higher attention and engagement, resulting in a positive mechanism for desired behavior change [23,25,29,36,41,45].
Game/social dynamics set social norms, process signaling	Game dynamics create a microcosm of social norms between players and signaling of appropriate actions, resulting in the desired/designed behavior change [23-26,29,31,36,41].
Game mechanics reinforce rules and actions	The rules of the game create clear boundaries and direction for particular actions and desired behavior [23-25,28-31,36,40,41,48,49].
Clear objective/goals leverage internal motivators	Game objectives set attainable goals and motivate players with a sense of purpose, pursuit, and achievement toward the desired behavior [25-29,31,32,35,36,38,39,42,44,45,48-50].
Rewards, success, and failures leverage external motivators	Consequences leverage external motivators and operant conditioning to achieve desired behavior [23,25,27-29,36,38,40-42,46-48,51]
Challenging repeated play leads to competence, mastery, and expertise	Incremental improvement provides feedback on mastery and expertise leading to repeated desired behavior [23-25,28,38,49].
Spectatorship influences atmosphere, community, and expectations	Being observed or creating community reinforces expectations and social norms of desired behavior [24,25,29,31,34-41,43,45,49]

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Effective Game Mechanic Design Elements in Behavior Change Interventions

Overall, in the design and intervention process, there was strong evidence that games developed by local teams rather than distant experts had better outcomes [22,27,30,31,40,41,43-45]. Games that were pilot tested and whose designs were reiterated with target users resulted in better behavior change outcomes [22,27,29,41-43]. Delivery alongside or as an adjunct to other learning modalities was also successful and supports the theory of complex interventions [27,28,32,34,35,38,40,46,47]. There was also evidence that repeated play and training or practice of the delivery of the ruleset and gameplay assisted the outcome [23,34,36,39-41,43,45]. Games were better received and had greater impact when behavior change goals were clearly defined and targeted through the game mechanics, for example, in Kaledo, a collection mechanic will incentivize the players to collect health food–based tokens to redeem in real-life cafeterias for healthy diets [22-26,29-31,34,36,37,39,41-43,45-49].

Dynamic and Context Elements That Explain Outcomes of Games

Considering and leveraging the dynamics of how players interact with each other to support or enhance the experience resulted in better outcomes [23-26,29,31,36,41]. Interventions that accounted for the development of social norms, process signaling between players, and tapping external and internal motivators were more successful in their goals [22-26,30,31,41,43]. Games that were more fun and enjoyable to play had better information uptake and engagement [23,25,29,36,41,45]. Furthermore, designing the user context and emotions was seen to have an impact on the experience of play. Being observed through spectatorship or creating a community appeared to reinforce expectations and social norms of the desired actions of players [24,25,29,31,34-41,43,45,49].

Reality Testing: Translation of the Intent of Gamification Into Practice

Games seem to translate well to practice but some intent of the games can be lost, and a framework needs to consider this. There was evidence demonstrating that games that are not enjoyable have limited replayability or have novelty effects that led to poor engagement and less targeted behavior change [23,34,36,40,41,43-45]. This was also seen in games with poor contextual design where information can be misinterpreted or even lead to unwanted effects (Textbox 1 and Table 3) [35,47,50].

Textbox 1. Factors that reduce the efficacy of games targeted for behavior change.

Contextual or mechanism factors

- Laborious or unattractive game designs for immersive play [35,47,50]
- One-off play or limited replayability [23,34,36,40,41,43-45]
- Simple question-and-answer games sometimes that are not engaging or immersive [33,34,36,40,42,44]

Table 3. Theories for games targeting behavior leading to poor behavior change outcomes.

Theories	Behavior change outcome
Not fun or enjoyable leads to low engagement	Unpleasant experiences are unlikely to be engaging or repeated and result in no behavior change
Limited replayability reveals novelty effects	One-off play and wearing off of the game novelty results in lack of repetition and lack of lasting behavior change
Poor contextual design leads to misinterpretation	Missing context dues can lead to poor knowledge translation/misinterpretation and unwanted effects

We refined the preliminary program theory based on the CMO analysis. We propose the following modification of the preliminary program theory in order to help future design of games to achieve health behavior change to include more structure and guidance around these results.

Proposed Framework for Designing Effective Behavior Change Games

Define Goal: Diagnosing the Behavior to Change

Like designing any tool for a task, one should start by considering the desired outcome. Define the behavior to change first. List the barriers to behavior change to target.

Create Order With Game Mechanics: Building Rules to Deliver the Desired Outcome

There are several mechanisms that can be considered processes to achieving this, such as leveraging behavioral insights, reward and punishment, or information delivery. The mechanism chosen is the skeleton from which the core rules and game mechanics can be built.

Expect Chaos Dynamics: Consider How the Individual, Group, and Context Will React to the Rules

Context of the target players, environment, and other constraints at this stage should be reflected upon to consider the dynamics of the player and game interactions.

Make it Fun (Aesthetics): Make it Enjoyable for Higher Engagement

To maximize engagement, the aesthetics of the story, visual values, and physical values of the game are important for the player experience. Games that are not fun will not engage players and lead to minimal behavior change.

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Pilot: Test and Reiterate the Product

A reiterative piloting and feedback loop should be the final stages of the game design.

Measure the Desired (and Undesired) Outcomes

Measure with appropriate scientific methods the behavior change defined. Measure the desired outcome, second-order effects, and undesired outcomes. Consider measuring the short and long game of possible behavior change extinction and novelty effects.

Use Other Resources: Use as a Tool in a Toolkit

Delivery alongside other mediums will likely increase the desired changes. Including stakeholders as another resource in this toolkit will likely lead to more effective outcomes.

Discussion

Principal Findings

The results of this realist review reveal game elements that contribute to health behavior change. Specifically, when careful consideration is used to define and target the behavior, game designers can enhance the game's mechanics, dynamics, aesthetics, and elicitation of emotions in a refined process to create the best conditions for successful behavior change. We propose the suggested framework for the game design process that will ensure relevance across different regions, settings, and age groups. Behavior change interventions are complex in their nature due to the ways in which behaviors develop in different contexts for different individuals [12,13]. The framework is built on the broad aspects of game principles by Robson et al [15] using broad categories of game mechanics, dynamics, and emotions with the addition of aesthetics from the report of Hunicke et al [16]. There are several proposed game design frameworks in the literature—18 were found in a recent systematic review [17]. Our review suggests that the game design process is mainly focused on the objective of the game. This includes economic frameworks focused on viability in a marketplace for a game and logic framework to ensure that the game makes sense. The more relevant frameworks for behavior change are those focused on the psychology and participant experience. Many of these subset frameworks focus on digital games [52,53] or psychological aspects of gamification in relation to ethics [19,54]. In contrast, the framework outlined in our review aims to be applicable not only to tabletop or board game designs but also to any game being digitized. The review of Mora et al [17] shows that a framework should be actionable and cover the generic basics and should have human-centered design principles at its center.

Game designers need to consider all aspects of the game experience to achieve the desired behavioral outcomes. First, consideration should begin by defining the target behavior and identifying ways to promote this target behavior through the game. Second, a decision should be made on how the game rules will work to reinforce the desired change (game mechanics). This may include examples such as rewards, punishments, goals, collections, information retention, or physical challenge. Next, reflect on the context of how the players interact with the game and with each other (game dynamics) and if this can be leveraged for the behavior change target. This could include cooperation, negotiation, persuasion, competition, subversion, bargaining, spectatorship, charity, and the pursuit of mastery. Finally, fun and enjoyment of the player should be considered, as without engagement, there will be no desired intervention effect. The aesthetics and emotions of the game should not be forgotten as the experience of play should be pleasant and engaging for the maximum effect. This also includes the role of the spectators, observers, and nonparticipants in the process.

Our evidence synthesis demonstrates that our preliminary program theory was insufficient and that the overall design and delivery process has some impact upon the success of the intervention. Games designed by local designers with context-specific knowledge, in addition to training delivered to users in multiple exposures combined with other mediums appear to be important considerations to achieve target behavior change outcomes [23,34,36,39-41,43,45]. Having interested stakeholders and games without novelty effects and good replayability result in feedback loops for incremental gains toward behavior change [23,34,36,40,41,43-45]. Stakeholders who know the types of players and the contexts well should design the games or have significant input. This is consistent with literature that local deliverers of behavior change interventions are more successful at delivering local needs in context [55]. Moreover, reiteration and pragmatic pilot testing in a real-world setting is likely to lead to better outcomes [56,57].

Games appeared to be effective in all age groups, but most of the literature is on participants younger than 18 years. It could be hypothesized that games are only effective for children and adolescents. However, games should be considered a legitimate engaging behavior change intervention for all ages, if the game design process considers the target audience. There is a trend for serious games to be considered a legitimate intervention for a purpose other than pure entertainment. The literature is expanding across all age groups and multiple industries, including applications in military, government, education, corporate business, and health care [58]. There are a range of potential effects that can be seen with interventional games, including perceptual, cognitive, behavioral, affective, and motivational impacts, knowledge acquisition, content understanding, and learning [59,60].

Pitfalls in Game Design

Several pitfalls were identified for game designers to avoid in each key area. First, the failure to diagnose a specific behavior to target with the game was a common error in the studies reviewed. Games developers need to define the behavior change first, list the barriers to behavior change to target, and follow a structured design process to decide which elements of game mechanics can be leveraged to target this behavior. This process was best done using local teams who have knowledge of the players and context. Second, the dynamics between how the players will interact with the game and with each other should be considered in the context of play to avoid unwanted effects. Thinking about second-order behaviors and possible unwanted effects could be considered here in the design process. Once

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the rules and predicted play behavior have been established, the user experience and user interface (or aesthetics) should be considered to enhance fun and engagement. Games in which aesthetics was not given due attention were undesirable or not engaging. Finally, the design process should include pilot testing, wherein behavior change will be assessed carefully and a multi-intervention approach will be considered to maximize the impact of the desired outcome, assuming through realism that no 1 intervention will work for everyone.

Metagaming

The concept of metagaming can also be considered for advanced game design strategy. Designers can abstract outside of the rules of the game to consider how the player will use the game outside of its intended rules or environment [61]. The concept of metagaming is defined as a player taking action outside the rules or design of a game such as developing higher strategy, cheating, applying outside information, or strategy not intended by the mechanics [62,63]. Designing for metagaming behavior is not usually part of the core mechanics but can be intentionally thought of in the design process to add another engaging layer to the game experience. For example, the game itself could be used as a collectable item for a desired outcome, having the physical world around the game change the way it is played or reward cheating in the core mechanics to improve the likelihood of desired behavior outcomes. Considering the target behavior at the metagaming level can advance the engagement and is an interesting opportunity for behavior change game designers.

Limitations

First, this review was limited by the small number of published studies using games as an intervention. This limits the potential analysis of the topic. Second, the included studies were of varying degrees of methodological quality. One concern is that only a limited number of papers used in this review showed evidence of behavior change in their interventions. Most studies focused on education and knowledge changes owing to the short intervention period and lack of follow-up. As is common in a realist review, we did not exclude papers based on methodological quality. Finally, working definitions of games and the wording of interventions that could be considered games is likely not consistent. It is possible that this review did not contain all evidences on game-like interventions owing to the varying definition of what “is” a game, for example, setting blood pressure target goals could be considered a game element. However, we performed further hand searching of the reference lists from the included studies to mitigate this limitation. This review is also limited in the framework being applicable only to tabletop game contexts.

Conclusion

Games can be used as a successful intervention tool for effective behavior change. The ability of games to achieve behavior change is a product of their design—to address a clearly defined problem. Using a realist review methodology, we synthesized evidence from published papers and proposed a framework for game design. This framework outlines the considerations for making a game for a behavior change intervention. Game designers should consider elements of this framework specifically early in the design process to map the context and flow of participants through play, help create the mechanics that govern the rules, consider the dynamics and experiential aspects of playing, and maximize the aesthetics of the play experience. This framework is designed to achieve the best possible interventional results without unintentional outcomes in a realist context, acknowledging that not all interventions will work for all participants in all contexts. Game designers can use this framework to improve the quality of the design process for behavior change interventions. Future work in this field is to apply further realist lens to serious game design in fields outside the context of behavior change or tabletop games or to test this thesis framework in the context of digital game design.

Conflicts of Interest

None declared.

Multimedia Appendix 1
Full search string.
[DOCX File , 14 KB - games_v9i1e23302_app1.docx]

Multimedia Appendix 2
Realist review papers included in the full review.
[DOCX File , 31 KB - games_v9i1e23302_app2.docx]

Multimedia Appendix 3
PRISMA checklist.
[PDF File (Adobe PDF File), 43 KB - games_v9i1e23302_app3.pdf]

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Abbreviations

CMO: context-mechanism-outcome

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Short Paper

Adolescent Problem Gaming and Loot Box Purchasing in Video Games: Cross-sectional Observational Study Using Population-Based Cohort Data

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Abstract

Background: Video game loot boxes, which can typically be purchased by players or are given as reward, contain random virtual items, or loot, ranging from simple customization options for a player's avatar or character, to game-changing equipment such as weapons and armor. Loot boxes have drawn concern, as purchasing loot boxes might lead to the development of problematic gambling for adolescents. Although parental problem gambling is associated with adolescent problem gambling, no studies have evaluated the prevalence of loot box purchases in adolescents' parents.

Objective: This study investigated the association between loot box purchasing among adolescents and parents, and problem online gaming in population-based samples.

Methods: In total, 1615 adolescent (aged 14 years) gamers from Japan responded to a questionnaire regarding their loot box purchasing and problem online gaming behaviors. Problem online gaming was defined as four or more of the nine addictive behaviors from the Diagnostic and Statistical Manual of Mental Disorders. The adolescents' primary caregivers were asked about their loot box purchasing.

Results: Of the 1615 participants, 57 (3.5%) reported loot box purchasing. This prevalence did not differ according to primary caregivers' loot box purchasing, but adolescents who purchased loot boxes were significantly more likely to exhibit problem online gaming (odds ratio 3.75, 95% CI 2.17-6.48).

Conclusions: Adolescent loot box purchasing is linked to problem online gaming, but not with parents' loot box purchasing. Measures to reduce these behaviors should target reducing addictive symptoms in young video gamers.

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KEYWORDS

loot box purchasing; gambling; adolescents; primary caregivers

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Introduction

Video game loot boxes have drawn concern over similarities to problem gambling [1]. A gambling disorder is typically characterized by adult issues with gambling. However, loot boxes feature heavily in video games marketed to children who pay for game items/rewards with real-world currency [2]. Loot boxes contain randomized content, and therefore their value is unclear at the time of purchase. Young people are more likely to exhibit impulsive behaviors and to find risk-taking appealing. Therefore, purchasing loot boxes might lead to developing problematic gambling among adolescents [3]. The relationship between problem gambling and loot box purchasing appears to be moderated by problem online gaming or excessive gaming [4,5].

The prevalence of loot box purchasing is poorly understood in adolescence. Most studies on the role of loot box purchasing in problem gambling used adult samples [4,6,7], with only two empirical studies utilizing adolescent samples. One study recruited participants via an online bulletin board, which may have included more varied gamers engaging in loot box activities instead of only adults [8]. Another study used a community sample from the Danish Civil Registration System [9]. However, no studies have evaluated the prevalence of loot box purchases in adolescents' parents, even though parental problem gambling is associated with adolescent problem gambling [10-12]. It is unclear whether loot box purchases among adolescents are triggered by parental behavior or by their own problem online gaming. Such understanding constitutes an important basis for developing policies and interventions to prevent or mitigate the risks related to adolescent loot box purchasing.

This study investigated the association between loot box purchasing in adolescents and parents, and problem online gaming in population-based samples.

Methods

Participants

Data were obtained from the Tokyo Teen Cohort (TTC) study, an ongoing, prospective, and population-based birth cohort study on adolescents and their primary caregivers [13]. The TTC investigates adolescents' health and development, with the details of the study described elsewhere [14-16]. All procedures involving human participants were performed in accordance with the ethical standards of the associated institutional research committees, and in adherence to the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all adolescent respondents and their caregivers included in the study. The TTC's study protocol was approved by the institutional review boards of the Tokyo Metropolitan Institute of Medical Science (approval number 12–35), SOKENDAI (Graduate University for Advanced Studies; 2012002), and the University of Tokyo (10057).

This study sample included 2667 adolescents (aged 14 years) born between September 2002 and August 2004, along with their primary caregivers. Data were collected via a self-reported questionnaire.

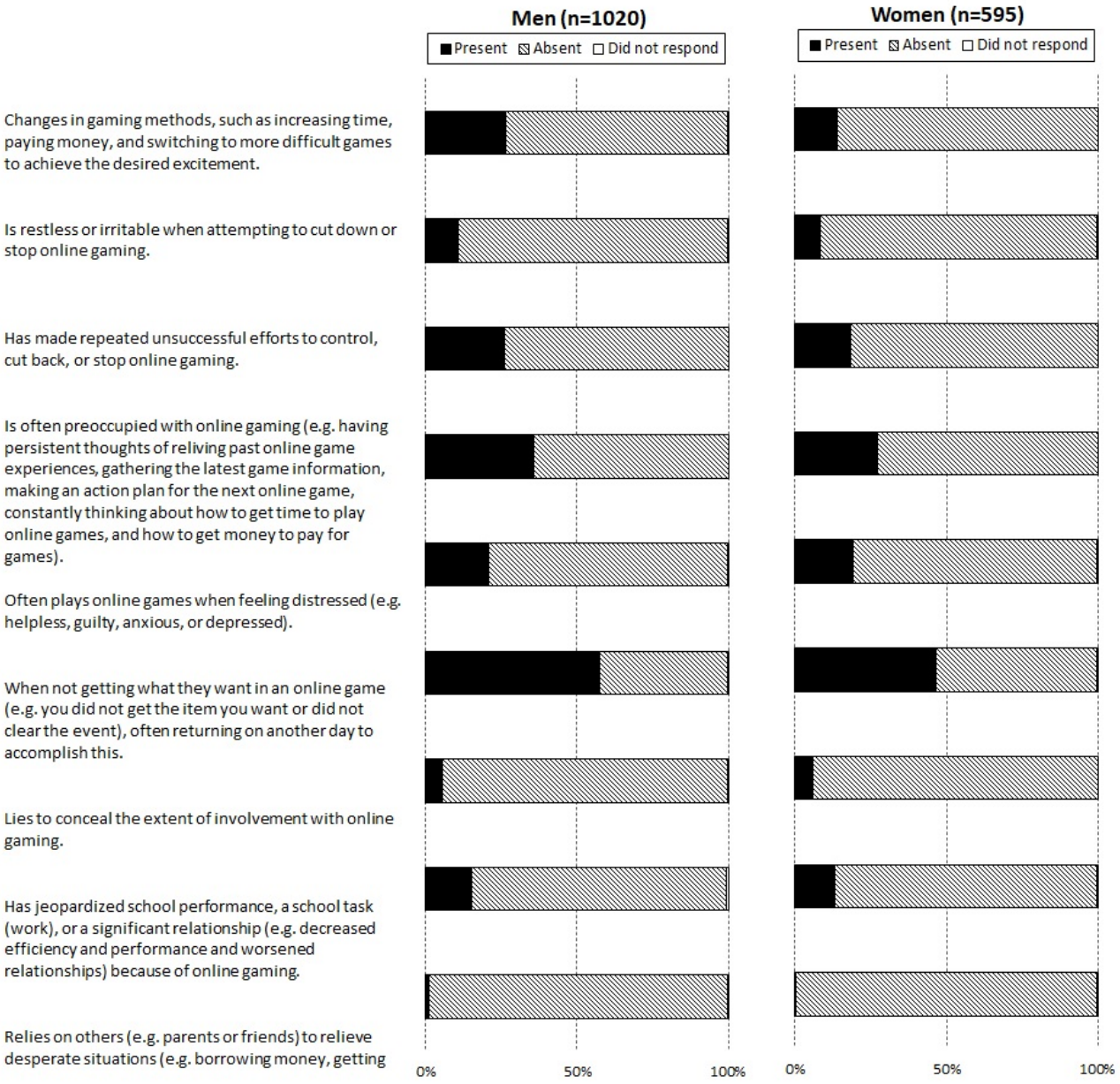
Procedures

In the questionnaire, adolescents and their primary caregivers were asked whether they played online video games. Participants who answered "yes" were defined as "gamers," who then answered further questions regarding loot box purchasing. A single question was used to determine whether they spent real money on items/rewards in games, excluding payment for game consoles and software fees.

Adolescents were also asked about problem online gaming. The proposed criteria for gambling disorder in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition were used to assess problem online gaming. The criteria were restated as nine questions (Figure 1) to assess the presence of certain behaviors or emotions related to addiction in online games within the past 12 months. Based on the proposed criteria, respondents who reported four or more behaviors were defined as having problem online gaming.

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Figure 1. Presence of problem gambling behaviors among adolescent gamers.



Statistical Analysis

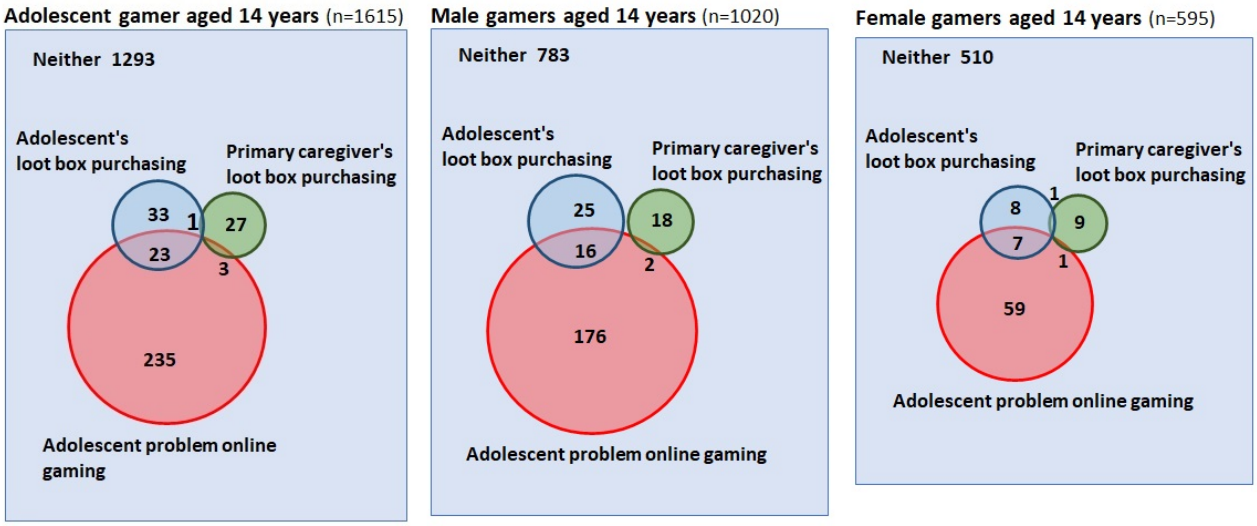
Odds ratios (ORs) of problem online gaming according to the presence of loot box purchasing were calculated using univariate binomial logistic analysis. As the association between loot box engagement and problem online gaming is stronger for women than men [8,9], the analysis was stratified by sex.

Results

Of the 2619 respondents (1392 men, 1227 women), 1615 adolescents answered that they played online games (1020 men, 595 women). Of these 1615 gamers, 57 (3.5%) reported purchasing loot boxes (4.0%, 41/1020 men; 2.7%, 16/595 women). Of the 1615 primary caregivers of adolescent gamers, 514 (31.8%) played online games and 31 (6.0%) reported purchasing loot boxes. The prevalence of adolescent loot box purchasing did not vary according to primary caregivers' loot box purchasing (χ^2_1=0.009, *P*=.93; Figure 2).

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Figure 2. Venn diagrams of loot box purchasing and problem gambling in adolescent gamers.



Of the 1615 gamers, 261 (16.2%) exhibited four or more addictive symptoms in online gaming (194/1020, 19.0% men; 67/595, 11.3% women); 23 adolescents reported purchasing loot boxes and met the criteria for problem online gaming (Figure 2). Logistic regression analysis revealed that the likelihood of problem online gaming was significantly higher for adolescent gamers who purchased loot boxes than for those who did not (OR 3.75, 95% CI 2.17-6.48). The OR was greater in female gamers (OR 6.73, 95% CI 2.42-18.72) than in male gamers (OR 2.88, 95% CI 1.51-5.51).

Discussion

Principal Findings

Loot box purchasing was reported by 3.5% of 1615 gamers aged 14 years, whereas only 1.9% of their parents reported this behavior. Parental loot box purchasing did not correlate with that of adolescents. Problem online gaming was more frequently observed, which was evident in 15.7% of adolescent gamers, and those who purchased loot boxes were significantly more likely to exhibit problem online gaming.

The link between loot box purchasing and problem online gaming found in this study is consistent with previous reports in adult populations [4,5]. As reported in previous studies [8,9], male adolescents were more likely to be gamers and purchase loot boxes than female gamers. However, unlike other gambling behaviors, adolescents' loot box purchasing does not appear to be inherited from their parents. Measures to reduce loot box purchases should target reducing addictive symptoms in young online gamers.

Our study's strength lies in confirming the absence of a correlation between the loot box purchasing behaviors of early adolescents and those of their parents. Multifaceted support for self-regulation in combination with parenting techniques for limiting loot box purchases is recommended for children gamers [17]. Our findings suggest that parental techniques to prevent problem online gaming may also be helpful to reduce loot box purchases.

Limitations

This study has some limitations. The cross-sectional design did not allow us to draw conclusions regarding the causal relationship between loot box purchasing and problem online gaming. A longitudinal study would be beneficial to evaluate how loot box purchasing in early adolescence correlates with other addictive behaviors in later adolescence and with gambling in adulthood.

Conclusions

Parental loot box purchasing did not correlate with that of adolescents. Adolescents who purchased loot boxes were significantly more likely to exhibit problem online gaming. Measures to reduce loot box purchases should target reducing addictive symptoms in young video gamers.

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Conflicts of Interest

None declared.

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Abbreviations

OR: odds ratio
TTC: Tokyo Teen Cohort

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Corrigenda and Addenda

Correction: Using Serious Games for Antismoking Health Campaigns: Experimental Study

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The correction will appear in the online version of the paper on the JMIR Publications website on March 8, 2021, together with the publication of this correction notice. Because this was made after submission to PubMed, PubMed Central, and other full-text repositories, the corrected article has also been resubmitted to those repositories.

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Corrigenda and Addenda

Correction: The Effect of a Health Game Prompt on Self-efficacy: Online Between-Subjects Experimental Survey

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In "The Effect of a Health Game Prompt on Self-efficacy: Online Between-Subjects Experimental Survey" (JMIR Serious Games 2021;9(1):e20209) the author noted one error.

In the originally published paper, the Corresponding Author address for author Priscilla Haring inadvertently listed the incorrect country as well as the incorrect country code in the author's phone number. The originally published Corresponding Author address was listed as follows:

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The correction will appear in the online version of the paper on the JMIR Publications website on March 22, 2021, together with the publication of this correction notice. Because this was made after submission to PubMed, PubMed Central, and other full-text repositories, the corrected article has also been resubmitted to those repositories.

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