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Original Paper

FightHPV: Design and Evaluation of a Mobile Game to Raise Awareness About Human Papillomavirus and Nudge People to Take Action Against Cervical Cancer

Tomás Ruiz-López[1], MSc, PhD; Sagar Sen[2], MSc, PhD; Elisabeth Jakobsen[3], MSc; Ameli Tropé[3], MD, PhD; Philip E Castle[4], PhD; Bo Terning Hansen[1], PhD; Mari Nygård[1], MD, PhD

[1]HPV Research Group, Department of Research, Cancer Registry of Norway, Oslo, Norway
[2]Simula Research Laboratory, Oslo, Norway
[3]Cancer Registry of Norway, Oslo, Norway
[4]Albert Einstein College of Medicine, New York, NY, United States

Corresponding Author:
Mari Nygård, MD, PhD
HPV Research Group
Department of Research
Cancer Registry of Norway
Ullernchausseen 64, 0379 Oslo, Norway
Oslo,
Norway
Phone: 47 95181886
Email: mari.nygard@kreftregisteret.no

Abstract

Background: Human papillomavirus (HPV) is the most common sexually transmitted infection globally. High-risk HPV types can cause cervical cancer, other anogenital cancer, and oropharyngeal cancer; low-risk HPV types can cause genital warts. Cervical cancer is highly preventable through HPV vaccination and screening; however, a lack of awareness and knowledge of HPV and these preventive strategies represents an important barrier to reducing the burden of the disease. The rapid development and widespread use of mobile technologies in the last few years present an opportunity to overcome this lack of knowledge and create new, effective, and modern health communication strategies.

Objective: This study aimed to describe the development of a mobile app called FightHPV, a game-based learning tool that educates mobile technology users about HPV, the disease risks associated with HPV infection, and existing preventive methods.

Methods: The first version of FightHPV was improved in a design-development-evaluation loop, which incorporated feedback from a beta testing study of 40 participants, a first focus group of 6 participants aged between 40 and 50 years and a second focus group of 23 participants aged between 16 and 18 years. Gameplay data from the beta testing study were collected using Google Analytics (Google), whereas feedback from focus groups was evaluated qualitatively. Of the 29 focus group participants, 26 returned self-administered questionnaires. HPV knowledge before and after playing the game was evaluated in the 22 participants from the second focus group who returned a questionnaire.

Results: FightHPV communicates concepts about HPV, associated diseases and their prevention by representing relationships among 14 characters in 6 episodes of 10 levels each, with each level being represented by a puzzle. Main concepts were reinforced with text explanations. Beta testing revealed that many players either failed or had to retry several times before succeeding at the more difficult levels in the game. It also revealed that players gave up at around level 47 of 60, which prompted the redesign of FightHPV to increase accessibility to all episodes. Focus group discussions led to several improvements in the user experience and dissemination of health information in the game, such as making all episodes available from the beginning of the game and rewriting the information in a more appealing way. Among the 26 focus group participants who returned a questionnaire, all stated that FightHPV is an appealing educational tool, 69% (18/26) reported that they liked the game, and 81% (21/26) stated that the game was challenging. We observed an increase in HPV knowledge after playing the game (P=.001).

Conclusions: FightHPV was easy to access, use, and it increased awareness about HPV infection, its consequences, and preventive measures. FightHPV can be used to educate people to take action against HPV and cervical cancer.

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KEYWORDS

papillomavirus vaccines; educational technology; uterine cervical neoplasms; papillomavirus infections; primary prevention; secondary prevention; early detection of cancer; mobile applications; health education; learning

Introduction

Background

Human papillomavirus (HPV) is the most common sexually transmitted virus globally [1]. There are over 120 HPV genotypes, over 40 of which infect the anogenital epithelium in women and men. Approximately 14 HPV types are referred to as high-risk types; these can cause cervical cancer and are responsible for a significant proportion of cancers of the vagina, vulva, penis, anus, and oropharynx [2]. Some low-risk HPV types can cause genital warts [3]. Barrier contraceptives, such as condoms, may partially protect against the transmission of HPV infection [4,5]. Approximately 5% of all cancers worldwide are caused by HPV infection [6]. Cervical cancer is one of the most common female cancers worldwide, with global estimates of approximately 530,000 new cases and 270,000 related deaths in 2012 [7]. Although newly developed prophylactic HPV vaccines represent a primary prevention method that can be used to protect against HPV infection and reduce the future burden of cervical cancer [8], screening has been used in many countries for decades as a secondary prevention method. Consistent, periodical cervical cancer screening by cytology or HPV testing can detect precancerous lesions, and if treated in a timely fashion, the progression of these lesions to invasive cervical cancer can be prevented [9].

In almost all countries with a cervical cancer screening program, there is a segment of population (approximately 20%) that does not attend screening, in which a significant proportion of cervical cancers is diagnosed [10-13]. Although mass media campaigns have been effective in improving screening attendance, they have been shown to only have a temporary effect [14]. Awareness of and adult education regarding disease are some of the most important determinants of participation in health services [15,16]. This emphasizes the need for efficient, sustainable, culturally appropriate, and societally relevant approaches to inform women of the disease risks associated with HPV infection, ways to prevent HPV infection, and recent changes in cervical cancer prevention strategies, especially in younger generations who use different media to get their (health) information.

Mobile technologies have developed rapidly since 2007 [17]. In the United States, 95% of the residents have a cell phone and 77% own a smartphone [18]. People spend more time on smartphones than on desktop computers [19], using smartphones up to 5 hours per day on average [20]. Therefore, smart devices appear to be a suitable platform to communicate information to target audiences. Apps for mobile technologies, or *mobile apps*, represent a very promising, burgeoning market and medium to disseminate interventions aimed at changing health behaviors [21]. Mobile apps have the potential to change the way health care systems communicate with their patients in a positive way and facilitate the delivery of patient-centered health care globally [22,23]. Mobile games are among the most popular mobile apps [24], followed by mobile apps for social media platforms, such as Facebook, Twitter, and Snapchat. Information shared through these platforms can influence how we think and act [25].

Given the popularity of mobile games, the concept of gamification, that is, using the elements of game playing for other purposes, has been launched as a novel and promising tool to improve health communication. The idea is that using game thinking and game mechanics in nongame contexts will help users engage in the learning process and thus facilitate knowledge acquisition, positive health-related attitudes, and positive behavioral changes [21,26,27]. As social media is extensively used by the majority of smartphone users, making game aspects shareable through social networks can influence how others think and act. This is called social nudging via gamification, which helps others stick to health-promoting behavior [28]. Social nudging is rooted in the very nature of human behavior, as we are actively involved in the lives of friends and relatives when they discuss lifestyle choices.

Objectives

In this paper, we describe the principles and processes preceding the launch of a digital game–based learning tool for mobile devices, FightHPV, which aims to communicate concepts that are relevant to understanding the principles behind the sophisticated technology currently used to prevent HPV-related diseases such as cervical cancer.

Methods

FightHPV was developed in a stepwise manner, applying an iterative design methodology [29]. We originally intended to target only women of cervical cancer screening age, that is, between 25 and 69 years, in Norway. However, as FightHPV aims to leverage the power of mobile communication and social nudging by allowing players to share information about HPV and cervical cancer with their social network, we expanded the target group to include adolescent boys and girls to inform them about HPV vaccination and other preventive methods.

A multidisciplinary team of software engineers, graphic designers, and medical professionals created a skeleton for gamifying selected story lines or narratives with connected text messages to convey health education. The team included researchers in the field of cancer, HPV infection and the management of the Norwegian Cervical Cancer Screening Program. On the basis of extensive domain knowledge, the team decided on a set of characters, gaming rules, game mechanics, and alternatives for social networking. For the programming, Swift for iOS (Apple Inc) and Java (Oracle) for Android (Google) were used. Crash reporting tools from Fabric (Google) were bundled with FightHPV so that the team could receive information on possible malfunctions during the execution of the program; this allowed us to identify and correct software bugs before public distribution. FightHPV was then evaluated by beta testing and 2 focus groups.

The beta testing study included 40 employees of the Cancer Registry of Norway, who were external to the present project but were knowledgeable about cancer. Focus group 1 comprised 6 women aged between 40 and 60 years, who were members of the Norwegian Women's Public Health Association. Focus group 2 comprised 23 high school students (10 girls and 13 boys, aged between 16 and 18 years) living in Oslo, Norway (Table 1).

Participants in the beta test were invited to download a private (nonaccessible to the general public) release of FightHPV for Android through the testing facilities provided by Google Play. They were encouraged to advance as far as they could in the game and report any flaws they encountered. After beta testing, summary data were collected from Google Analytics for quantitative descriptive analytics, which captured different actions performed by players, including wins, fails, and retries for each level. Following approval from the Data Protection Agency, improved versions of FightHPV were made available through Google Play for Android and TestFlight for iOS.

Participants of focus group 1 downloaded version 2 of FightHPV to their mobile devices, 1 week before attending the focus group discussion held in Oslo, Norway. Participants of focus group 2 downloaded version 3 of FightHPV on their mobile devices and played the game for 2 hours before the focus group discussion held in the participants' school. Focus group 2 was selected to evaluate how a generation that is used to playing mobile games would respond to a game that teaches lessons about the generation's own health and its willingness to share the information learned with others who may find it relevant. Although the focus of this research project is cervical cancer, we included boys as they can benefit from vaccination both directly and indirectly [30] and can nudge others to adopt a healthier lifestyle on the basis of the knowledge they acquire from playing FightHPV.

Focus group discussions lasted 45 to 60 mins, were semistructured and led by members of the research team, and were audiotaped at the consent of the participants. For focus group 2, girls and boys had separate sessions, moderated by a female and male member of the research team, respectively. The goal of these discussion sessions was to receive both general and specific feedback on FightHPV. A predetermined set of questions about knowledge and attitudes on HPV and sexual health and how information regarding sexual health can be conveyed to the public was used as a guide. At the start of each focus group discussion, participants were encouraged to freely discuss their experiences with FightHPV, addressing the usefulness of a mobile game to disseminate information about health and their willingness to share this information with others.

Of the 29 individuals who participated in focus group discussions, 26 (4 from focus group 1 and 22 from focus group 2) returned a questionnaire about the game and a test of their knowledge of HPV before and after playing the game. The data from 22 players from focus group 2 were analyzed and tested for statistical significance using the nonparametric Wilcoxon signed rank test. The tests were 1-sided, with null hypotheses of no difference in scores before and after, against alternative hypotheses of a higher score after playing FightHPV.

FightHPV is part of a project approved by the Norwegian Regional Ethical Committee (REK 2015/1926) and the Institutional Data Protection Officer. A liability and copyright terms and conditions of the game, along with logos from Oslo University Hospital and the Cancer Registry of Norway, have been incorporated into the app to enhance players' trust in the content.

Table 1. Characteristics of participants in beta testing and focus groups.

User group	Participants, n	Age range (years)	Gender	Description
Beta test	40	30-60	Male and female	Employees of the Cancer Registry of Norway
Focus group 1	6	40-60	Female	Members of the Norwegian Women's Public Health Association
Focus group 2	23 (10 girls, 13 boys)	16-18	Male and female	High school students

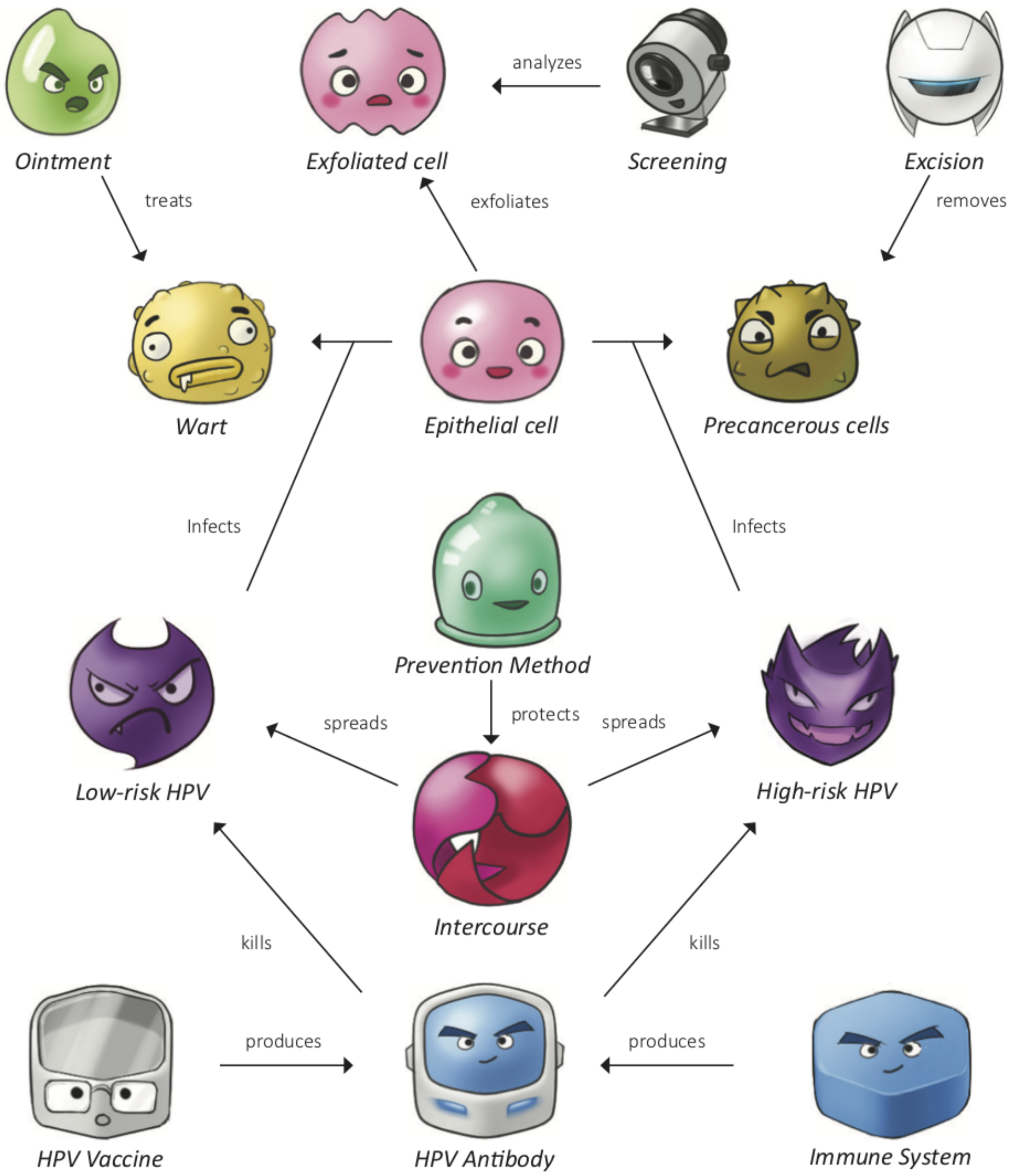
Results

Description of FightHPV Game Mechanics, Characters, Game Rules, and Story Lines

To mimic the real-world relationships between HPV and the human body, FightHPV includes a set of characters with game rules that define their interactions. The characters (in italics) *Epithelial cell*, *Low-risk HPV*, *High-risk HPV*, *Wart*, *Ointment*, *Precancerous cells*, *Excision*, *Intercourse*, *Prevention Method*, *HPV Vaccine*, *Immune System*, *HPV Antibody*, *Exfoliated cell*, and *Screening* are displayed on a frame of game board–based puzzles. The main character is *Epithelial cell* and the challenge is to unify all the *Epithelial cells* on the game board by changing their positions swiftly, using as few moves as possible. The other characters interact with each other and with *Epithelial cell* (Figure 1).

At the beginning of each level, the characters appear on concentrically placed hexagons or rings, and the player is instructed to solve the challenge by moving the characters on the game board. Each character has a maximum of 6 surrounding positions, which can be taken by any other character on the game board. Furthermore, 2 characters located next to each other trigger the predefined interaction, which can be either positive or negative for the player to solve the challenge (Multimedia Appendix 1).

Figure 1. Characters and interactions between characters, that is, game rules in FightHPV. *Low-risk HPV* (human papillomavirus) can transform *Epithelial cell* to *Wart*. *Wart* can be transformed back to *Epithelial cell* using *Ointment*. *High-risk HPV* can transform *Epithelial cell* to *Precancerous cell*. *Precancerous cell* can be transformed by an *Excision* back to *Epithelial cell*. *Intercourse* will release both types of viruses onto the board, but this can be averted by applying *Prevention Method*. *Immune System* in response to *HPV Vaccine* transforms into a powerful *HPV Antibody*, which can kill both *Low-risk HPV* and *High-risk HPV*. Finally, *Exfoliated cells* can be tested by *Screening*.



We selected, amended, and simplified health messages into 60 puzzles (levels), which were then organized into 6 episodes with separate story lines, containing 10 levels each. Information is communicated using relevant characters with predefined rules, which appear in advancing levels within each episode. Gaming difficulty advances gradually from level 1 (simple) to level 10 (more difficult) within each episode. Every new level in the episode either repeats previously introduced information in a more demanding puzzle or introduces a new piece of information.

In episode 1, Epithelial cells, we communicate the role of intact/healthy epithelial tissue and introduce the game mechanics to the player. The actual HPV life cycle is dependent on exploiting the biological process within the epithelial tissue, which covers the outer surfaces of the cervix [31]. Established persistent infection in the epithelium is a necessary trigger for the carcinogenic transformation of epithelial cells. This is a long process that starts with minor cellular abnormalities and advances to more definitive premalignant changes, cancer, and death.

The properties of low- and high-risk HPV to transform normal epithelial cells to warts [3] and precancerous lesions [32], respectively, are presented in episode 2, Low-risk HPV, and episode 3, High-risk HPV. Episode 4, Prevention, presents the spread of both low- and high-risk HPV through unprotected sexual intercourse. The player can use the character *Prevention*

Measure (which resembles a condom) to protect *Epithelial cell* against HPV in the game. In episode 5, HPV Vaccine, the principles of vaccination are conveyed by presenting the interplay among the characters *Vaccine*, *Immune System*, *Low-risk HPV*, and *High-risk HPV* [30,33]. Screening principles were gamified in episode 6, Screening.

Communication of health information is reinforced with short messages that appear at the beginning of each puzzle and are related to the goal players have to accomplish. Longer articles that relate to each episode have been written for the mobile app, and links to these articles are available on the puzzle screens for users who want to read more in-depth information.

In-Game Feedback and Social Networking

Several elements are used to increase players' motivation to complete the levels, and there are several conditions that determine whether players have successfully completed the levels. Effects and actions in the game are highlighted with sound and character animation to encourage players to retry the level in case of failure. Immediately after completing the level, a score on the scale of 1 to 5 stars with appropriate animation and sound is displayed for the player. The numerical score is calculated on the basis of the remaining number of movements and the time taken to solve the puzzle for that level (Figure 2). Players' scores are also ranked in leader boards, and players can share their scores and compete with other users. Players can replay a level to find better solutions and increase their score. To further support player engagement and replay, we included achievements. Effects and actions in the game are highlighted with contextual sounds and character animation. For networking, we programmed direct links to all the social network platforms already loaded in the player's device (Figure 2).

Players with a Norwegian personal identification number, that is, those residing in Norway, have been invited to participate in a separate study to determine the effect of FightHPV on cervical cancer screening attendance (results will be presented in a future article). Once enrollment in that study is finalized, the option to participate in the study will be removed from the FightHPV app.

Design-Development-Evaluation Loop of FightHPV

Development of the first version of FightHPV started in April 2015, and beta testing was carried out in December 2015. Version 2 of FightHPV was released and discussed with focus group 1 in June 2016 and version 3 of FightHPV was released and discussed with focus group 2 in November 2016 (Figure 3). Feedback was discussed thoroughly by the team to decide on how to incorporate the suggested changes. Characters, episodes, levels, textual information, in-game communications, and competitive elements were changed in response to the feedback from the focus groups. FightHPV was available to download for free in the App Store and Google Play in Norway in November 2016 and worldwide in April 2017.

Overall, the appearance of all 14 animated characters in version 1 of FightHPV was positively received by participants. They thought that the characters were amusing and cute and that there was a clear distinction between positive and negative characters. In response to the feedback, characters *Intercourse* and *Prevention Method* were slightly changed. Game mechanics, that is, how to move the characters on the game board, was intuitively understood by participants. However, the instruction session on how to solve puzzles was made more explicit and easily available throughout the game (Table 2).

Figure 2. In-game feedback and social networking in FightHPV. Screenshots from immediate feedback to players when they (a) complete or (b) fail a level. Players are encouraged to (c) share their score on social media to drive user acquisition and engagement. An example, (d) shows how users can share their score on Twitter.

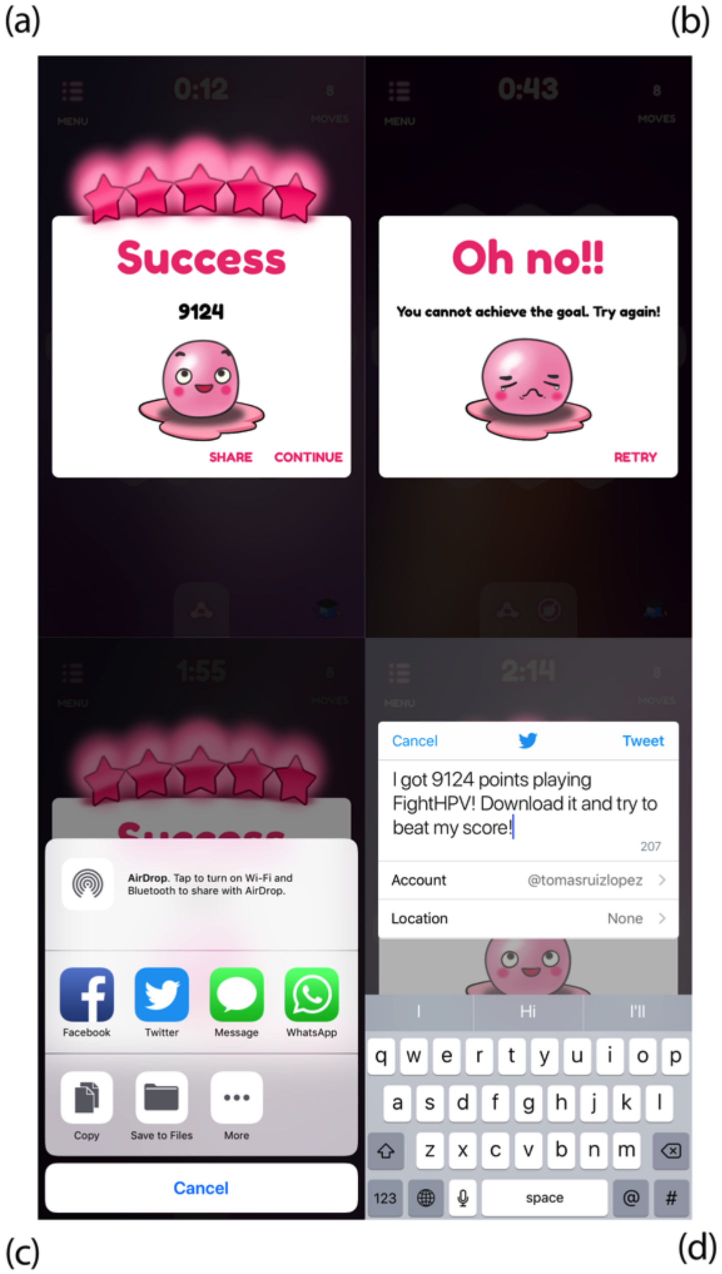


Figure 3. Timeline of the design-development-evaluation loop of FightHPV. Development of FightHPV started in April 2015.

Table 2. Summary of the changes in the design of FightHPV after each evaluation. Character names are in italics.

Feature	Initial design	After beta testing	After focus groups 1	After focus groups 2
Characters	14 characters were created	Appearance of *Intercourse* and *Protection Method* needed to be redesigned	—[a]	—
Episodes	60 levels were organized into 6 episodes. Each level was accessible sequentially, that is, only after the previous level was completed	—	Open access to all 6 episodes at any time. However, the 10 levels within the episode were accessible sequentially	—
Levels	Initial puzzle design	Adjusted difficulty for levels with highest proportion of failures	—	Adjusted difficulty for levels with highest proportion of failures
Textual information	Initial writing of human papillomavirus -related information	—	Reduce childlike tone to appeal to more mature audiences	Reduce technical language to increase understandability. Linked real-world images to characters to ease concept comprehension. *Learn more* links from game to longer content articles
In-game feedback	Success or failure only	Background music and sound effects added	—	Animations after game actions added
Competitive elements	Achievements and leader boards	—	Social features added to compare player's performance with others/friends	—
User interface miscellaneous	—	—	Ability to toggle music/sound on and off	Changed text font for readability

[a]No changes were made to this feature at this development stage.

All levels were accessible sequentially in version 1, meaning that the player had to complete all the levels in episode 1 before advancing to episode 2, and so forth. Data from Google Analytics (Table 3 and Figure 4) showed that episode 2 was played 450 times and was the most frequently played episode. Several peaks in failures and retries were shown for levels 5, 8, 12, 20, and 40, indicating that those levels were considerably more difficult than others and the players were more likely not to complete them. The frequency of actions after level 50 was negligible, and only 1 player out of 40 completed the whole game. During beta testing, the game was played most frequently during the weekend following its release (December 14-16, 2015), immediately after downloading, and during the holiday season (December 23-31, 2015). Assessing how players navigated among different sections of the app revealed that 13% (5/40) of participants read the longer articles, whereas all participants played the game by solving puzzles.

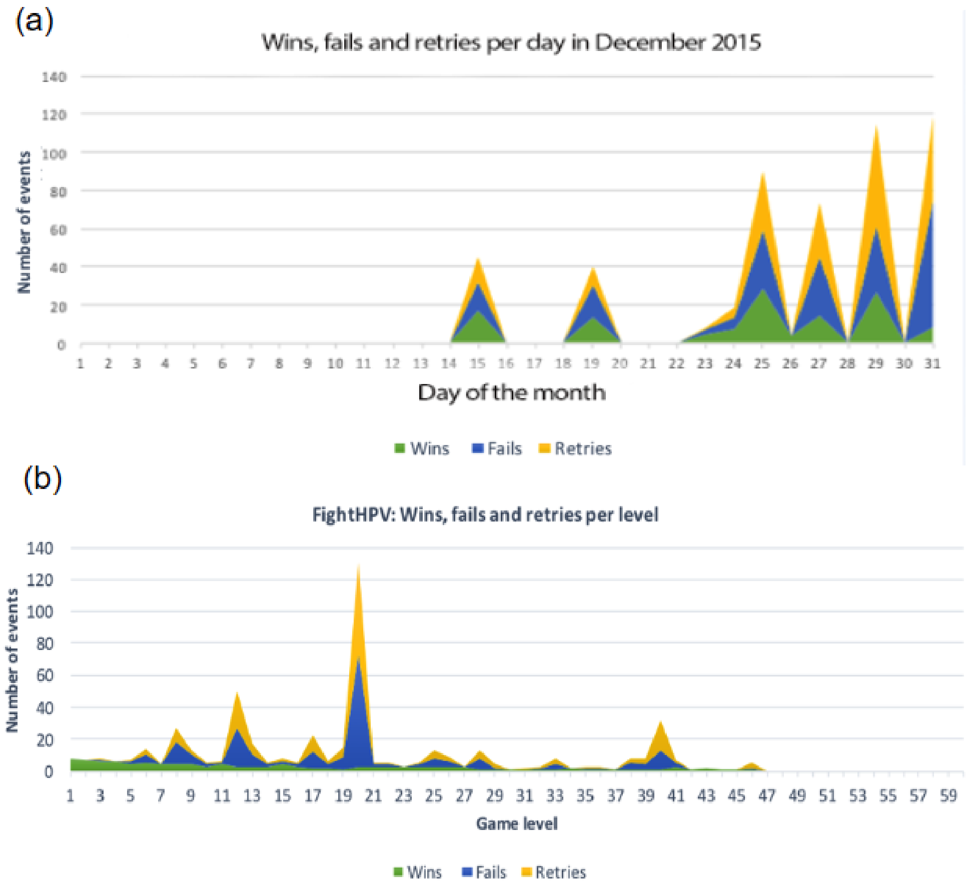
The feedback from beta testing and from Google Analytics demonstrated that players stopped playing the game if the level was too difficult, and without completing the level, there was no way around to advance to the next episode. We therefore simplified levels that were causing the most trouble and allowed direct access to every episode from the beginning of the game.

Table 3. Results from beta testing. Frequency of in-game events.

Episode	Game actions	Event count
1. Epithelial cells	Connecting cells on the board	307
2. Low-risk HPV[a]	Connecting cells on the board	459
2. Low-risk HPV	Using *Ointment*	354
3. High-risk infection	Connecting cells on the board	96
4. Prevention	Using *Prevention Method*	73
5. HPV vaccine	Generating antibody	27
5. HPV vaccine	Eliminating virus	72
6. Screening	Using *Exfoliated cell*	15
6. Screening	Using *Excision*	15

[a]HPV: human papillomavirus.

Figure 4. Results from beta testing. (a) Frequency of wins, fails, and retries per day during a period of 1 month (December 2015). (b) Frequency of wins, fails, and retries per level. HPV: human papillomavirus.



Textual information presented in the game, which reinforced the health message, was considered useful by all participants of the beta test group and focus groups. However, the first focus group felt that the tone of these messages was either too childish or too complicated. Longer articles, in contrast, were perceived as too technical. Short messages, longer articles, and the text that described the medical concepts early in the game were rephrased by the writer of the development team. The text font for the entire game was changed to improve readability (Table 2).

Upon user request, we added sound effects, background music, and animations to accompany important events, which enhanced feedback for the actions performed by the player during the game. We established a visual relationship among the characters, real images in the *Learn more* section, and allowed players to turn music and sound effects on and off. Furthermore, sharing on social media was incorporated into leader boards and achievements to drive user engagement (Table 2).

General Feedback on FightHPV From Focus Groups and Effect on Knowledge

The overall feedback from the focus groups was positive; out of the 26 participants who returned their questionnaire, all stated that FightHPV is an appealing educational tool, 69% (18/26) reported that they liked the game, and 81% (21/26) stated that the game was challenging. Participants from focus group 2 had little a priori knowledge about HPV and HPV-related diseases, whereas participants from focus group 1 reported medium to high knowledge. During the discussion session, participants in focus group 2 specifically raised questions about HPV and how it can affect their health. They found the game to be thought provoking and requested more information on HPV. The girls' group suggested that this type of health information should be mandatory in schools, and they considered information about HPV to be a relevant topic for their well-being. Of the 22 participants in focus group 2 who returned a questionnaire, all showed a statistically significant improvement in their knowledge about epithelial cells, HPV, and HPV transmission, with a median and interquartile range (IQR) that ranged from very low to low before playing FightHPV, to low and medium after playing FightHPV. Concepts about HPV vaccination were best understood, with the highest IQR (Table 4). All participants from focus group 2 were willing to share this information within their close social circles as they thought it would be beneficial for them.

Table 4. Knowledge about different topics related to human papillomavirus before and after playing FightHPV. Self-reported knowledge scores ranging from 1 (very low) to 5 (very high) among 22 participants of focus group 2 who returned the questionnaire.

Topics, scores	Scale					Median score (interquartile range)	*P* value (before vs after)[a]
	1	2	3	4	5		
Epithelial cells							.001
Before	14	4	4	0	0	1.00 (1.00- 2.00)	—[b]
After	3	9	8	2	0	2.00 (2.00-3.00)	—
HPV[c]							.001
Before	13	4	4	1	0	1.00 (1.00-2.00)	—
After	5	7	6	3	1	2.00 (2.00-3.00)	—
HPV vaccine							.006
Before	9	8	3	2	0	2.00 (1.00-2.00)	—
After	3	9	4	5	1	2.00 (2.00-3.75)	—
HPV transmission							.006
Before	11	6	4	0	1	1.50 (1.00-2.00)	—
After	5	9	3	2	3	2.00 (2.00-3.00)	—
Screening							.01
Before	16	3	2	1	0	1.00 (1.00-1.75)	—
After	10	8	2	1	1	2.00 (1.00-2.00)	—

[a]One-sided Wilcoxon signed rank test (N=22; 10 females, 12 males, all attending Ullern High School).

[b]Not applicable.

[c]HPV: human papillomavirus.

Discussion

Principal Findings

To the best of our knowledge, FightHPV is the first game to be released globally that gamifies health information about HPV and cervical cancer prevention. Participants in our user groups reacted positively toward educational game, and we were able to demonstrate a statistically significant positive effect of FightHPV on knowledge. In addition, focus group discussions revealed a significant lack of knowledge regarding HPV before playing the game, confirming the need for enhanced communication regarding HPV to the population. Furthermore, FightHPV was designed to create a network for knowledge sharing among people by employing social media, which has become integrated in our daily lives. Gamification and nudging have already been explored in other domains, such as fitness apps, with some success, which suggests this approach could be equally beneficial in communicating serious health information, raising awareness, and eliminating misconceptions about HPV.

Use of FightHPV can influence behaviors that are relevant to individual decisions regarding whether to receive HPV vaccination or attend cervical cancer screening. Social cognitive theories and empirical studies suggest that directed educational interventions that influence attitude, knowledge, and motivation are most effective when accounting for the context in which the targeted health behaviors take place [34]. As social norms shaped by social media had a devastating effect on HPV vaccination in Japan and Denmark [35,36], we wanted FightHPV to be easily shared in social circles, not only to engage more people in the game but also to share correct information and send a reminder about the importance of screening to family and friends.

To improve individual learning, we incorporated the following features into FightHPV, which are typical in digital game–based learning [37]: (1) a set of rules and constraints that described relationships and effects among characters, (2) several dynamic responses to players' actions, for example, sound, scoring, animations of effects, and characters, which communicate if a player made a right or wrong move; (3) direct access to episodes with different levels of difficulty, enabling learners to experience a feeling of self-efficacy, (4) gradual advancement in learning outcome within an episode. The combination of amusing characters with animation was seen as entertaining and increased player willingness to repeat levels and enhance cognitive changes, which is an important characteristic of digital game–based learning. To enhance player/learner motivation and engagement in acquiring new knowledge, we created story lines that would most help the layperson to understand virus transmission and what actions can be taken to avoid viral infection and cancer progression. We drew a parallel between the relationships among HPV concepts and typical video game quests, for example, the enemies—*Low-risk HPV* and *High-risk HPV*—trying to threaten other characters, that is, the *Epithelial cell*, and a hero, that is, the player, who needs to use tools (ie, the characters *HPV Vaccine* and *Screening*) to defeat the enemy. Visually appealing characters with interactive animations were created to further increase players' motivation to advance in or to repeat the game.

Beliefs that HPV infection and cervical cancer are not real threats to an individual's health and fatalistic beliefs that nothing can be done to reduce one's risk of dying from cancer have been reported as barriers that prevent women from attending screening and/or accepting to be vaccinated against HPV [37,38]. Interactive animation of characters according to player's moves and gaming rules created settings, which bridged the gap between abstract concepts of the natural history of cancer and a person's own body and helped to personalize the information. For example, the *Intercourse* character illustrates the main route of HPV transmission among humans. A character, *Prevention Method*, was also introduced, which helps the player get protected against HPV released from *Intercourse*. As a result of how these characters behave in the game, the puzzles featuring them become harder, depending on how long it takes to use a *Prevention Method*. This helps to communicate the importance of prevention. The episode *HPV Vaccination* presents 3 characters: (1) the *Immune System*, which is not able to fight HPV by itself, (2) the *HPV Vaccine*, which gives powers to the *Immune System* to fight HPV, and (3) the *HPV Antibody*, which appears after *HPV Vaccine* and has the ability to clean the board of HPVs.

We acknowledge that the applied interaction between characters and rules represents a considerable simplification of the real-life situation. On the other hand, simplification allows us to communicate a few take-home messages and address the principle of the increasing difficulty of levels within the episodes to provide a good gaming experience for player.

Appropriate instructions have been shown to help learners target relevant information and affect cognitive processing [38]. However, instructions given in the context of a digital-based learning game are thought to be playful and not focus on educational goals, thus eliciting shallower cognitive processing. To improve learning effectiveness, we presented textual information as well, either as short sentences or long articles, to influence deeper cognitive processes. Short sentences appeared at the beginning of each level and were purposely designed to be in a dialogue form, as if the characters in the game were telling a story. In this way, players can relate the text they read to the puzzle they are solving and vice versa. Although text information is easily bypassed for a better gaming experience, players can solve puzzles more easily if they pay attention to the text information. Furthermore, focus group discussions showed that FightHPV provoked players to think about their own behavior related to HPV and raise questions such as, "When was the last time I attended screening?" "Did I have unprotected sexual contact?" and "Have I been exposed to the virus?" In this way, players were able to personalize the information and relate their own life experiences to what they were learning.

FightHPV was also designed to trigger the desire to do something for others: "Should I vaccinate my children?" "Does my mother, sister, wife, daughter, friend, know how frequently they should go to screening?" Players are encouraged to share information with their relatives and acquaintances so that, even though they may not ever play, they can receive the information that we want to transmit. It is somewhat surprising that social nudging has not been used more actively in intervention trials to influence behavior; however, it is gaining attention [34].

Although HPV-related health messages are well suited for gaming, it took us approximately 1.5 years to develop FightHPV, and we encountered several challenges. The design-development-evaluation loop proved to be a useful method to develop different aspects of the game. At the start, the results from beta testing reassured us that using puzzles in a board game format engaged the players and that the mechanics of the game were simple and easy to learn, which made the game intuitive and easily approachable by almost all age groups without any previous gaming knowledge. However, along with being simple, the mechanics should also provide an adequate challenge to keep players engaged. To avoid user frustration at the early stages of the game, or boredom and lack of challenge at the end, it must have an increasing level of difficulty [39]. In the very early stages of development, we discovered shortcomings in the progression of difficulty in the game by using Google Analytics. Objective, numerical data feedback on failures, and retries on specific levels were essential to understand which part of the game was too difficult. To fine-tune the progression of the difficulty levels, we proposed the use of computational methods to decide the difficulty level, under the assumption that a level was equally hard to solve for a human and a computer. A recent paper described the formalization of the game board and the characters in a constraint program to solve FightHPV levels [40]. The solution of the constraint program was the sequence of moves to go from the initial state to a final state in which the winning condition is met.

An important part of raising awareness about HPV prevention through FightHPV is to attract as many users as possible and engage them to play through all the levels in the game. In this way, they will receive all the important health messages. Furthermore, receiving information repetitively over several playing sessions will help the user retain this knowledge for the future. Achievements and leader boards are commonly used game elements that increase user engagement. In addition to completing the levels in FightHPV, we created 44 side missions that users can complete by playing levels multiple times. Each time players complete one of these missions, they get a badge acknowledging their achievements. Global leader boards were created on the basis of the sum of players' scores in each level. Replaying some levels can help players get better scores and rank higher on the leader board. As FightHPV has been designed for the mobile platforms Android and iOS, we used Google Play Games and Game Center, respectively, to implement these features. They also include some social features so that players can compare their results with friends' results and challenge them, thus increasing user acquisition and engagement.

Although FightHPV was developed in the Norwegian context, it is technically simple to expand or modify the content of the game. The organization of the information into episodes allows developers to introduce new topics with minimal technical effort. For example, in Africa, it might be relevant to add an episode to communicate the interaction between HIV and HPV. Translation of the content to other languages is technically simple; however, we suggest that each country should evaluate the local context and communicate correct guidelines for vaccination and cervical cancer screening. Furthermore, short textual messages can be redesigned into pictograms to reach a wider audience. Hence, FightHPV can be adapted for use in different cultural and medical contexts.

Limitations

This paper describes our experiences in creating the very first game-based learning tool to convey simplified health information on HPV to a layperson. A few, if any, textbooks were available to provide guidance on how to design such a tool or to provide information on the pros and cons of using different development methods. We strongly feel that the iterative design, which has been widely applied in software engineering for agility and realizing a good product or market fit, was an optimal choice. Arguably, enhanced size and compositions of the evaluation groups could have improved the variety of the feedback; however, we were able to evaluate and redesign the app on the basis of almost all of the relevant suggestions provided by the user groups. The development team might have benefited from incorporating aspects of cognitive psychology in the evaluation of the feedback from the user groups. However, we feel that the methodology used was sufficiently rigorous to conform to a traditional systematic approach. Employees of the Cancer Registry of Norway participated in the beta test and most of these people are familiar with the concepts surrounding HPV and cervical cancer. They essentially tested only the playability of the game, without paying much attention to the medical content. This was observable because of the low number of visits to the information section of the app (Google Analytics, data not shown).

Focus group 1 had a small sample size (6 women), and although the women's qualitative feedback led to several game adjustments, it is not possible to suggest that these modifications would have appealed to the entire intended target group. Focus group 2 comprised high school students who were not of screening age, which is between 25 and 69 years in Norway. Although the game and the medical information it communicated were of interest to these participants, it is hard to extrapolate the same level of interest to the screening-eligible age group. It was also hard to know if the participants would have the attention span required to learn about every concept communicated in the game. This is primarily because of app fatigue and the availability of a wide range of apps. We did not observe significant barriers to the discussion of sensitive issues, perhaps as girls and boys were interviewed separately. In addition, there were no dominant voices in any of the focus groups to steer the discussion in only one direction. All focus group discussions included people who either had the Android phone/tablet or an iPhone/iPad based on the iOS operating system. The game was not developed for other mobile platforms; however, the market share for other mobile platforms is low in Norway.

Conclusions

We have successfully designed and released the game-based learning tool FightHPV, which at the time of this study, had been downloaded more than 12,000 times in more than 45 different countries on the Android and iOS platforms. Engineering, biology, medicine, epidemiology, art, and technology interventions were incorporated to create a modern platform to convey relevant information on basic biology and anatomy, which is needed to make informed decisions on personal health. Furthermore, FightHPV also has the possibility to nudge people to take action against cervical cancer. The proposed concept is flexible and scalable, and the content of the game can be expanded to large populations and different cultures. The usage of apps for health purposes is receiving some attention, thanks to initiatives such as Research Kit from Apple, as it enables people to create platforms for the communication and monitoring of different aspects of health. However, more studies are needed to quantify the extent to which these apps and games can actually change health behavior.

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Conflicts of Interest

PEC reports receiving HPV tests and assays at a reduced or no cost from Roche, Benton Dickinson, Arbor Vita Corporation, and Cepheid for research. The remaining authors declare no conflicts of interest.

Multimedia Appendix 1

Game mechanics of FightHPV.

[PDF File (Adobe PDF File), 2MB - games_v7i2e8540_app1.pdf]

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Abbreviations

HPV: human papillomavirus
IQR: interquartile range

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Review

Developing Theory-Driven, Evidence-Based Serious Games for Health: Framework Based on Research Community Insights

Sarah Verschueren[1], BSc, MSc, PhD; Connor Buffel[2], MBT; Geert Vander Stichele[1], PharmD, MSc

[1]MindBytes BVBA, Merksplas, Belgium

[2]MindLab Interactive AI Inc, Edmonton, AB, Canada

Corresponding Author:
Sarah Verschueren, BSc, MSc, PhD
MindBytes BVBA
Schoondreef 7
Merksplas, 2330
Belgium
Phone: 32 476753516
Email: sarahverschueren@hotmail.com

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This is a corrected version. See correction statement: https://games.jmir.org/2020/2/e18515/

Abstract

Background: The idea of using serious games to effectuate better outcomes in health care has gained significant traction among a growing community of researchers, developers, and health care professionals. Many now recognize the importance of creating evidence-based games that are purposefully designed to address physical and mental health challenges faced by end users. To date, no regulatory resources have been established to guide the development of serious games for health (SGH). Developers must therefore look elsewhere for guidance. Although a more robust level of evidence exists in the research literature, it is neither structured nor is there any clear consensus. Developers currently use a variety of approaches and methodologies. The establishment of a well-defined framework that represents the consensus views of the SGH research community would help developers improve the efficiency of internal development processes, as well as chances of success. A consensus framework would also enhance the credibility of SGH and help provide quality evidence of their effectiveness.

Objective: This research aimed to (1) identify and evaluate the requirements, recommendations, and guidelines proposed by the SGH community in the research literature, and; (2) develop a consensus framework to guide developers, designers, researchers, and health care professionals in the development of evidence-based SGH.

Methods: A critical review of the literature was performed in October to November 2018. A 3-step search strategy and a predefined set of inclusion criteria were used to identify relevant articles in PubMed, ScienceDirect, Institute of Electrical and Electronics Engineers Xplore, CiteSeerX, and Google Scholar. A supplemental search of publications from regulatory authorities was conducted to capture their specific requirements. Three researchers independently evaluated the identified articles. The evidence was coded and categorized for analysis.

Results: This review identified 5 categories of high-level requirements and 20 low-level requirements suggested by the SGH community. These advocate a methodological approach that is multidisciplinary, iterative, and participatory. On the basis of the requirements identified, we propose a framework for developing theory-driven, evidence-based SGH. It comprises 5 stages that are informed by various stakeholders. It focuses on building strong scientific and design foundations that guide the creative and technical development. It includes quantitative trials to evaluate whether the SGH achieve the intended outcomes, as well as efforts to disseminate trial findings and follow-up monitoring after the SGH are rolled out for use.

Conclusions: This review resulted in the formulation of a framework for developing theory-driven, evidence-based SGH that represents many of the requirements set out by SGH stakeholders in the literature. It covers all aspects of the development process (scientific, technological, and design) and is transparently described in sufficient detail to allow SGH stakeholders to implement it in a wide variety of projects, irrespective of discipline, health care segments, or focus.

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KEYWORDS

health; computer games; digital; intervention; review; methodology

Introduction

Background

Many games and apps market themselves as tools or interventions to address health conditions and disease, yet they provide little explanation on their development, provide minimal information on real-world evaluation of their efficacy, and often reference poorly designed research studies [1-4]. Developers, designers, researchers, and health care professionals involved in the development of serious games for health (SGH) (further simply referred to as *developers*) now increasingly recognize the importance of creating evidence-based games that are purposefully designed using expertise, knowledge, and validated, quality data [1-7]. To be recognized as a nonpharmacological health care intervention and gain marketing approval from regulators, to obtain reimbursement from health care payers, or to gain CE approval when dispensing medical advice, developers will need to follow rigorous standards and provide a solid rationale for use and clear empirical evidence of the intervention's safety and efficacy [8]. This trend, together with an increasing focus on incorporating patient needs and preferences in the development process of health care interventions [9-11], has resulted in a paradigm shift in the development of SGH from a mainly game design orientation with a focus on user experience toward a more scientific approach that involves multiple stakeholders such as patients, clinicians, caregivers, payors, as well as regulators [12,13].

Developers who intend to market their SGH interventions to clinicians and patients will also need to deliver convincing evidence of the game's ability to safely achieve the intended outcomes if they wish to overcome the current barriers to uptake. As only a few validated tangible success stories exist, many clinicians are skeptical about the use of SGH in current health care practice. These barriers may hinder medical and scientific progress in certain fields and impact the investment risk associated with developing SGH. Although the development cost can vary greatly depending on complexity, graphical and technical design features, and the time spent on scientific substantiation and (clinical) evaluation, it typically ranges from ten to several hundred thousand dollars [14]. When complex three-dimensional motion graphics, community platforms, or large-scale clinical evaluation trials are involved, the development costs can even run up to several millions of dollars. Such large investments are risky, given the fact that many SGH address small market niches with limited potential for return on investment. Therefore, any potential barriers to uptake, such as lack of credibility and evidence of effectiveness, compound the investment risk for developers.

The Status Quo

To create theory-driven, evidence-based SGH, developers should collect and integrate scientific evidence and data throughout the entire development life cycle—from early stage theoretical work to later stage evaluation [1-3,5,7,15,16]. However, to date, there is no clear regulatory framework for the development of SGH beyond the type of evaluation data required (ie, evidence of risks and benefits). Regulatory requirements of SGH will likely depend upon their precise claims, and there are few transparent conditions that developers of minimal risk applications must meet before their products can be launched. This may also be the case for applications that are not obviously minimal risk as the developer must first engage regulatory authorities to determine what regulations they need to comply with.

In the absence of a regulatory framework, developers must look elsewhere for guidance on suitable approaches for developing SGH. Although a more robust level of evidence exists in the research literature, it is neither structured nor is there any clear consensus. The few resources that do exist are often focused on only a fragment of the development process, such as technology aspects or pedagogical aspects [17,18]. Others are described at such a high level that it is not possible for developers to implement such recommendations. Without clear consensus on frameworks, guidelines, and recommendations, developers must arbitrarily select which resources to follow.

This is in fact what happens. SGH developers currently use variable frameworks, differing guidelines, and alternative methodologies in SGH development [6,19]. The issue is further compounded by the fact that this emerging field is so multidisciplinary that each segment utilizes its own specific set of principles and frameworks to develop individual components. Moreover, development is often specialized to specific SGH classifications or target audiences [20,21]. Therefore, it is clear that SGH developers would benefit from the establishment of a defined set of requirements that represents the consensus views of SGH stakeholders [21]. Not only would this help increase SGH probability of success but it would also benefit the SGH community by raising the quality of SGH by providing the necessary evidence required by stakeholders. Moreover, it would also enhance the credibility of SGH developers and allow them to achieve a sustainable market share.

Objective

The objective of our research was to search the literature and identify and evaluate the requirements, recommendations, and guidelines proposed by the SGH research community on the development of SGH. This included recommendations on what inputs are required to guide the development, what data should be collected, how games should be tested, which stakeholders should be engaged, and what game design approaches should be considered. On the basis of the findings, a clear and easy-to-implement consensus framework was developed to guide developers in the development of theory-driven, evidence-based SGH.

Methods

Databases and Search Strategy

A critical review of the research literature was performed in October to November 2018. The following databases were searched electronically: PubMed, ScienceDirect, Institute of Electrical and Electronics Engineers Xplore, CiteSeerX, and Google Scholar. A 3-step search strategy was used. An initial limited search was undertaken using the search strategy (game OR games) AND (serious OR applied OR health*), where * represents a wildcard to allow for alternative suffixes. This was followed by an analysis of the text words contained in the title and abstract and an analysis of the index terms used to describe article. A second search using all identified keywords and index terms was undertaken across all above databases. Finally, the reference list of all identified reports and articles were searched for additional relevant studies. A supplemental search of guidelines from regulatory authorities was also conducted to capture the requirements of these specific stakeholders. Three researchers independently evaluated the identified articles.

Inclusion Criteria

Included papers were empirical research studies, literature reviews, opinion pieces, preliminary research, randomized controlled trials (RCTs), theoretical models, conference proceedings, conceptual frameworks, or design documents that (1) reported on the development or evaluation of a serious game for use in a health care context, (2) were published in English, (3) were published between January 2007 and November 2018, and (4) were peer reviewed.

Exclusion Criteria

Excluded were any articles that (1) contained abstract only, (2) reported on serious games with applications outside of health care (formal education, corporate training, business decision making, etc), and (3) focused on pedagogical or psychological theory with no link to serious games.

Coding

After screening, requirements relating to the development of SGH were extracted from each of the papers. These requirements were coded using the following steps, on the basis of a thematic analysis approach:

1. Requirements of SGHs that were described, identified, or documented within the included studies were collected verbatim.
2. Existing frameworks [2-5] within the included studies were evaluated to identify currently accepted terminology for various requirements. In cases of noncongruent terminology among frameworks, an established term was selected by 1 researcher and confirmed by the other 2 researchers.
3. The verbatim requirements from step 1 were reviewed individually, and duplicates (variations of the same underlying requirement) were removed. Again, the resulting term was selected by 1 researcher (CB) and reviewed and agreed by the other 2 researchers.
4. The requirements from step 3 were compared with the accepted terms from step 2 and, if deemed appropriate, the former were categorized within the latter. One researcher (CB) performed this step first and the coding was discussed and confirmed by the other 2 Researchers.

The coding was performed to facilitate understanding and to address parsimony, which is threatened by nonconsensus descriptions, terminology variations, etc.

Results

Search Results

Our initial search yielded 216 papers (excluding duplicates). Of these, 74 papers were included in the review. See Figure 1 for a flowchart of the combined searches, as per Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [22]. Analysis resulted in a list of 62 requirements for the development of SGH, proposed by the SGH research community. Some requirements were formulated on a meta-level, whereas others were more detailed and concrete. The requirements were therefore categorized to allow for a structured analysis. We identified 5 categories of high-level requirements, as well as 20 detailed (low-level) requirements. See Table 1 for an overview of the identified requirements and categories, and the corresponding papers.

Figure 1. Literature search flowchart.

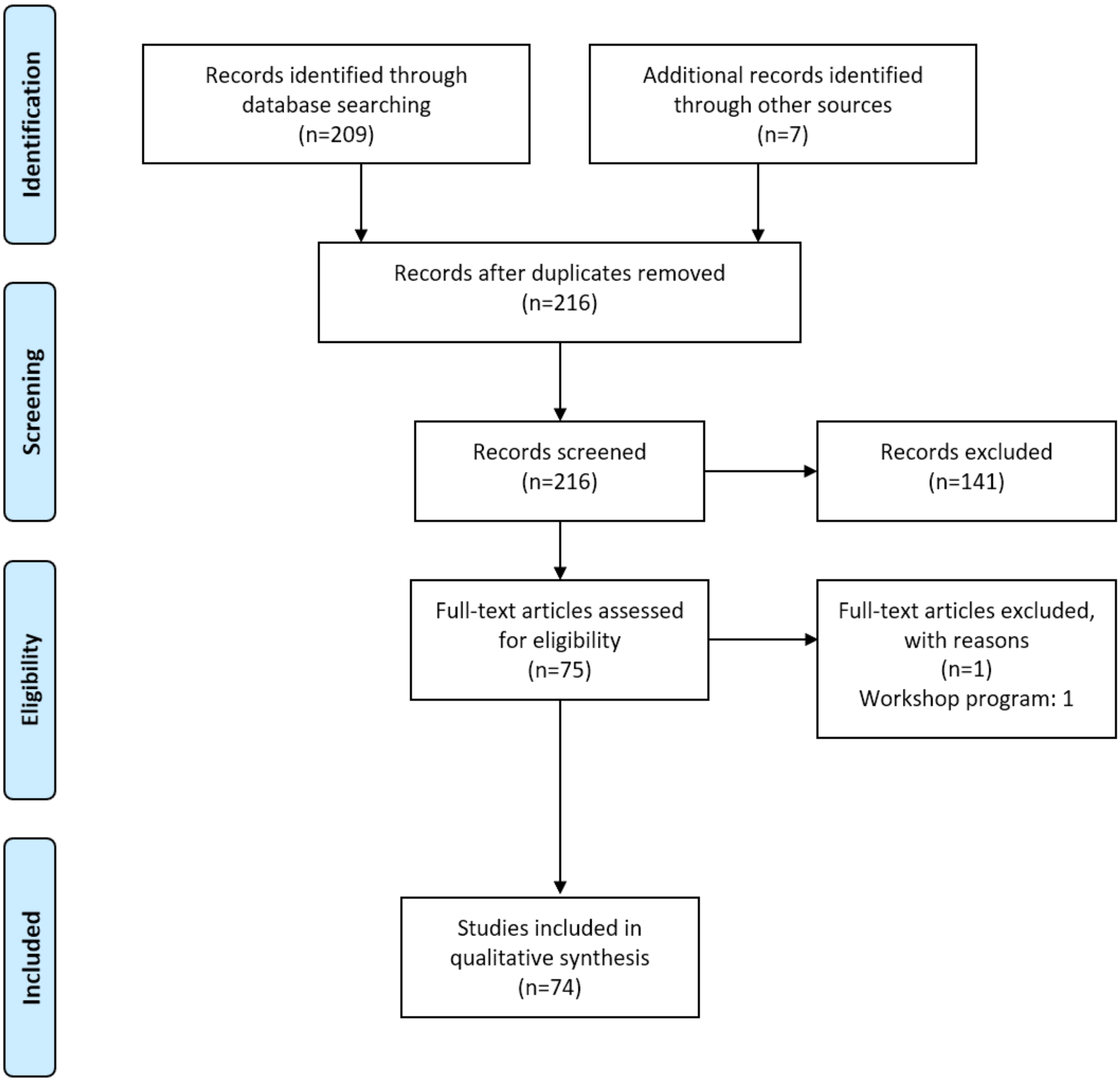


Table 1. List of high-level and low-level requirements and categories, and corresponding papers.

Hierarchy, category, requirements	References
High level	
Methodological approach	
Methodological approach	[2,3,5,7,16,23-28]
Multidisciplinary, participatory design process	[1,2,5-7,12,13,19,21,23-25,29-37]
Project management approach	[28,30,31,38-40]
Quality evaluation	[1-3,12,15,16,19,23-26,28,32,35,36,38,41-54]
Publish and disseminate findings	[1-3,16,24]
Low level	
Inputs	
Detailed profile of target audience	[1-3,5-7,23,33,43,45,51,55,56]
Target audience needs	[2,5,7,16,25,29,43,55,57-60]
Primary research goal	[1-3,12,15,23,25,33,43,55,58]
Models and theories	
Psychological theory	[1,2,4,23-25,27,53,56,58,59,61]
Game mechanics	[1,2,5,7,19,20,33,44,45,47,54-58,62-66]
Link between theories, mechanics, and game implementation	[7,19,21,23,26,44,45,55,58,62-64]
Game design	
Game type (genre)	[5-7,23,24,27,33,54,66,67]
Game authoring tool	[68,69]
Game platform	[5,6,33,67,70]
Game engine	[2,19,31,71,72]
Database	[2,19,43,70,72]
Data protection	[3,2,7]
Game objectives (explicit)	[1,3,6,19,20,23,33,47,48,53,54,56,65,73]
Narrative	[6,7,20,21,23,27,31,40,43,48,53,56,58,62,65,73-76]
Content	[6,7,19,23,36,54,65]
Aesthetics and graphics	[7,19,20,23,27,29,40,47,49,53,56,67,73]
Rules	[6,7,19,20,23,33,35,40,43,48,53,66,73]
Challenge	[6,20,29,31,33,35,40,53,56,58,77]
Interactions	[6,7,19,20,23,40,43,47,48,53,67,72,73]
Feedback	[7,19,20,24,33,53,54,56,58,59,62,67,78,79]

Evaluation Outcomes: High-Level Requirements

Methodological Approach

Out of 74 articles included for review, 11 articles stress the importance of employing an evidence-based, theoretically driven approach toward developing SGH. We identified both the research methodology and game design methodology requirements. The former includes the selection of clear outcome objectives at an early stage of development, as well as an evaluation of the game's ability to achieve those objectives at a later stage. Without considering an overarching research methodology at the outset, game developers will be challenged, or will be unable, to evaluate their games with well-designed research studies. Kato identified the following 3 questions that ought to be answered by a research methodological approach: Who is your target audience? What is the primary research goal? How can the goals be reached through gameplay (relevant theories and models) [3]? The latter includes a structured approach toward profiling the target audience, assessing content and technical requirements, selection of relevant game mechanics, and the structured translation of outcome objectives and relevant theories and models into the game design.

Multidisciplinary, Participatory Design Process

Out of 74 articles, 21 articles advocate involving stakeholders from various disciplines in the development process. This is not surprising as SGH have emerged at the nexus of a wide variety of disciplines such as game design, software engineering, user experience design, health care, psychology, pedagogy, and clinical research. Various stakeholders were cited as relevant for inclusion in the design process, including research experts, clinical experts, regulatory authorities, and policy makers. Many acknowledge that a multidisciplinary approach poses a challenge, as individuals with differing backgrounds use differing terminology; it also highlights the importance of different elements and may be unaccustomed to working closely with those outside of their field. Nonetheless, this challenge is considered a necessary one. Importantly, 16 articles explicitly suggest also involving the target audience in the process.

A participatory or user-centered design process uses input and opinion from end users to inform a game developer's choices. Although many acknowledge this as an important criterion for development, particularly in the field of mental health [37,79], there is currently no clear consensus on how the target audience should participate in game design or which elements it should inform. In fact, a recent meta-analysis on SGH with a behavioral focus indicated that certain types of participatory design may be more effective than others. Involving users in user testing and informant roles may be more beneficial than as co-designers, and the involvement in crucial aspects such as game dynamics elicited higher game effectiveness than involvement in trivial aspects such as esthetic components [29].

An iterative development approach was put forward by 6 articles. By developing SGH in segments, testing, and refining along the way, various stakeholders can inform at critical points of the development cycle, and development costs may be reduced.

Project Management Approach

Out of 74 articles, 7 articles highlighted the need for an approach that helps optimize the use of time and resources during development. This is particularly relevant for projects with limited development or research funding and SGH that focus on small market niches with limited potential for return on investment. There are particular challenges related to SGH that need to be managed: (1) helping multidisciplinary teams communicate and work together, (2) the slow process of research evaluation, and (3) the iterative prototyping process on the basis of user and expert feedback [30,38].

SGH developers increasingly use approaches inspired by Agile project management methods with SCRUM [31,39,80]. Agile is highly suited for complex projects where it is difficult to make a comprehensive implementation plan, and where many changes are expected along the way. Therefore, the approach focuses on conducting work in incremental iterations that can absorb new emerging insights and unanticipated changes. It is also based on the principle that multidisciplinary teams should self-manage their work and focuses on fostering communication and cooperation. However, there is currently no consensus on how to best adapt Agile approaches for participatory or user-centered design-focused projects [81,82] and how limits can be set on how far development iterations should go (how much feedback should be incorporated).

Quality Evaluation

Out of 74 articles, 30 articles cited the need to conduct quality evaluations and trials to validate SGH. This criterion is associated with the need to employ a high-level research methodology. The most important aspect of this criterion is likely the word quality, as there have been many trials of SGH, but only a few have reached a standard that can be considered high quality. Although it is evident that conducting a quality trial to validate SGH is a pivotal criterion, there is little consensus among the SGH community on what constitutes a quality trial. Many SGH trials only evaluate aspects, such as user experience, or technological aspects. Although this provides valuable information, it does not automatically allow for an assessment of how effective the game is at achieving the intended outcomes or the purpose for which it was designed. Drawing from the established research standards, a quality trial should include the use of a control group, participant randomization, an adequately powered trial, and objective measures of the primary and secondary outcomes.

Consistent with this thinking, several articles suggest that game developers should strive to carry out RCTs. Although these types of studies may not be necessary or relevant in all cases, RCTs are the still considered the gold standard for evaluating interventions in health care. Here, it is vital for game developers to work alongside stakeholders with expertise to determine the most relevant trial that will validate their games' claims. The elements that need to be investigated are dependent upon the development stage of SGH. For example, at an earlier stage, SGH stakeholders suggest investigating usability, user experience, and duration of play.

For true evaluation, which typically occurs at a later stage of development, SGH stakeholders have identified the importance of evaluating a game's efficacy (level to which it achieves intended objectives) in addition to its safety. The need for empirical evidence of efficacy and safety is consistent with requirements of health regulators, should SGH developers intend to have their product approved as a medical device.

Mixed-methods research, where both qualitative and quantitative data are gathered, is becoming an important methodology to investigate complex health-related topics. We identified several articles that highlight the need for better integration of these methods in the SGH research [41-43].

Publish and Disseminate Findings

SGH developers should endeavor to disseminate their findings to the SGH and wider health care community. This criterion was addressed in 5 articles. Consistent with other areas of health care where researchers are urged to publish all results, even negative ones, game developers should follow suit. This provides valuable evidence to the SGH community and may inform other researchers about what did and did not work for a target audience and game design. This is particularly important in assessing the effectiveness of serious games in relation to the constructs used in the design of the game.

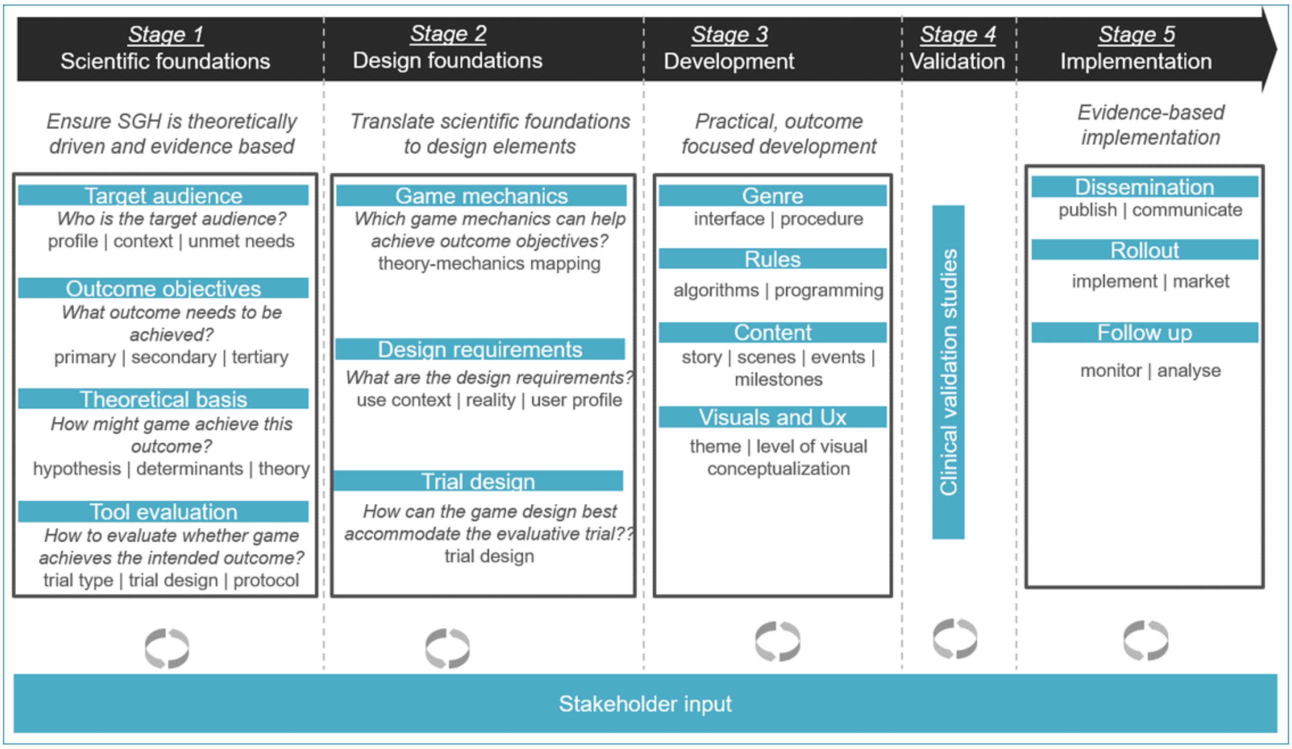
Evaluation Outcomes: Low-Level Requirements

In contrast to the high-level, or meta-level, requirements described above, the researchers also identified 20 low-level requirements from the SGH community. These requirements generally fell into 3 main categories: inputs, models and theories, and game design. Inputs represent the information and evidence that are integrated into the game from a conceptual perspective and cover the clinical or scientific content. SGH stakeholders clearly identified the importance of having a strong understanding of the target audience and their needs, clearly defining a research goal from the outset of a project. Models and theories were also identified as key requirements. This category represented the theories describing why a game would be expected to impact intended outcomes, and it also represented the associated link between these theories and game mechanics at the implementation level. SGH stakeholders suggest that without considering and integrating theories and models into SGH development, the resulting games are bound to be ineffective. The final and largest category of requirements contained all components related to the creation of the game itself. The category of game design comprised everything from defining one's game authoring tool, engine, platform, and genre to the rules, challenges, and feedback that are integrated within the game. As identified in the models and theories categories, SGH stakeholders noted the importance of mapping the game inputs and model and theories to the game implementation choices and mechanics. Without this link, it is not possible to evaluate if the evidence and thinking captured in the former categories have been truly translated into the game.

Proposed Framework

On the basis of the requirements suggested by the SGH research community, we propose a framework for developing SGH that comprises 5 distinct stages (Figure 2). Each stage has a specific focus and is informed by various stakeholders. Several iterations of development may occur within a given stage, progressively refining the SGH on the basis of testing with and feedback from relevant stakeholders. We will describe these stages as well as the stakeholder involvement in more detail below.

Figure 2. Proposed framework for developing serious games for health. SGH: serious games for health.



Stage 1: Scientific Foundations

Sound scientific foundations for the SGH should be established at the earliest stage of development. This will ensure that the final product is relevant, theoretically driven, and evidence based, in line with governing research methodological approaches. Although most developers tend to initiate the development process with a specific idea for an intervention in mind, the overarching objective of this stage is to assess at least conceptually and theoretically, on the basis of objective criteria, whether there is indeed a relevant medical unmet need for a clearly defined target audience who can be addressed with an SGH intervention. This stage typically comprises a topline review of the available literature on the target audience, disease status and impact, available treatment modalities, relevant clinical outcomes, psychosocial aspects (if any), and the governing health care landscape. To approach this task methodically, we propose that developers should focus on answering the following 4 questions: (1) Who is the target audience? (2) What outcome needs to be achieved? (3) How might SGH achieve this outcome? and (4) How can we evaluate whether SGH achieve the intended outcome?

Who Is the Target Audience?

A first, limited profile of the intended end users should be constructed. Information can be obtained through literature review, explorations of Web materials such as patient fora and websites, or consultation with subject matter experts (eg, medical specialists and patient organizations). At this stage, the profile should at minimum cover who the target audience is, the context in which the people function, the specific problems they face, and what their unmet needs are (eg, what alternatives are available to them and how well do these other interventions address those needs?). On top of this, some details may be required that are game- or topic-specific. For example, if the game intends to help children with disabilities improve their motor skills, it is important to understand the disease status and specific medical needs. For a game aimed at helping patients with schizophrenia reintegrate in society, the profile should also include an overview of the other stakeholders who play a role in these patients' lives and the relations among them (psychosocial details). At the other end of the spectrum, a game intended to educate medical professionals on how to handle ethical dilemmas would require some level of insight into the context in which these professionals make decisions, their learner profiles, and pedagogical needs. In stage 2 of the development, this first limited profile will be broadened to also include information regarding the specific game design needs of the target audience (eg, user experience needs and usability needs).

What Outcome Needs to Be Achieved?

Outcome objectives should be clearly formulated before any creative or technical development starts. These outcomes should be (medically) relevant, based on objective criteria. Due to the nature of SGH and their ability to educate, empower, and address multiple domains of health, we propose a biopsychosocial approach toward identifying relevant outcome objectives [83]. This model considers not only the biological factors of human functioning in the context of health but also the psychological and social factors. An often-cited example of where this is particularly relevant is the issue of therapy compliance. A majority of patients do not comply with the treatment regimens that could save their lives [84]. The solution to compliance issues is clearly complex, and psychological and behavioral factors play a prominent role. This requires developers to evaluate the biological, psychological, and social context of a disease or health condition [85].

Although outcome objectives may range from clinical to pedagogical, psychological, or behavioral, it is important to primarily identify a single primary outcome objective. This will steer the subsequent steps of game development and provide the greatest opportunity for success. This does not exclude a developer from identifying secondary (or even tertiary) outcome objectives as well. In fact, many cases will require the identification of various secondary outcomes that are closely linked to the primary outcome, and these need to be incorporated in the game construct as well. To give a few examples, if improved therapy compliance is the primary outcome objective, secondary outcomes may be to improve the quality of the patient's relationships or provide a more stable home environment (eg, for psychiatric disorders), or the secondary outcomes may be to overcome the patient's misconceptions or erroneous beliefs about the therapy (eg, for chronic patients fearing dependence on long-term medication) [86,87] or to make physical rehabilitation exercises more fun and rewarding (eg, for kids with motor skill disorders).

How Might Serious Games for Health Achieve This Outcome?

An often-overlooked step in SGH development is to formulate a hypothesis of how a game might achieve the intended outcome objective(s). Formulating such a hypothesis is a vital step toward the purposeful design of SGH and the evaluation of their causal effect on the outcome. First, developers should identify the outcome determinants. Outcome determinants are the underlying factors or parameters that directly or indirectly determine or influence the outcome objective. For example, if the primary outcome is to reduce peri-operative pain in children and the secondary outcome objectives are to reduce these children's peri-operative anxiety and stress (which are closely related to the primary outcome objective), it is important to establish what underlying factors contribute to pain, anxiety, and stress in children in this situation and evaluate which of these factors a game might positively or negatively impact, and how. The literature reveals that pain has sensory, emotional, cognitive, and behavioral components that are interrelated with environmental, developmental, sociocultural, and contextual factors [88]. One determinant is the level of pain medication administered to the child after surgery, with inadequate levels resulting in more pain. Delving deeper into the research literature reveals that parents play a key role in managing their child's pain in the home setting postsurgery. Any misconceptions parents have about pain medication may result in inadequate levels of pain relief, thereby increasing the child's pain experience. In this case, SGH may leverage pedagogical models and approaches toward educating parents about pain relief and correcting erroneous beliefs. Another determinant of peri-operative pain, anxiety, and stress is lack of control. Developers should therefore investigate whether SGH may help increase a child's feeling of control of the situation, for instance, through teaching coping skills or by allowing them to freely explore the peri-operative setting and events associated with it, so that they can anticipate what lies ahead.

The identification of these determinants and relevant underlying models or theories should occur in consultation with experts from relevant disciplines. From a biopsychosocial perspective, the link between psychosocial determinants and clinical outcome also needs to be understood and integrated in the game design. In addition, the role of the target audience as well as all relevant stakeholders needs to be evaluated. As such, this step of the process is one of identifying the various factors that contribute to the problem, grouping them, charting how they relate to and impact one another, and establishing hierarchies and relative weights of impact and importance. These insights will inform the game construct, narrative scenarios, and mathematical algorithms further on in the development process.

How Can We Evaluate Whether Serious Games for Health Achieve the Intended Outcome?

Before development starts, developers need to think ahead of how they plan to evaluate whether the game achieves the intended outcome(s). In 2012, Kato first formulated guidelines for conducting high-quality evaluations of SGH [1]. These suggest conducting randomized (clinical) trials that include adequate numbers of participants as well as control groups, the use of objective outcome measures alongside self-reports, monitoring and reporting potential negative side effects, and consulting research experts early on to guide the design of quality trials (eg, measures, n numbers, statistical power, and trial length).

Game evaluation should also include an evaluation of broader intervention characteristics, such as perceived relevance, user experience, and user friendliness. The particular characteristics that need to be evaluated vary depending on the objectives, and they may include satisfaction of needs (competence, autonomy, and relatedness), ability to engage, level of motivation, and competence autonomy. Ideally, a mixed-method methodology is used, in which both quantitative (eg, surveys) and qualitative (eg, focus groups and interviews) data are collected for analysis and evaluation.

This evaluation can be done throughout the development process through a series of iterative tests with the target audience and other stakeholders, using standard measures such as Intrinsic Motivation Inventory and Player Experience of Need Satisfaction Scale [89,90].

Stage 2: Design Foundations

Game developers can draw from a wide range of game mechanics, design, and technological features to construct SGH. If the SGH are to achieve the intended outcomes, the choice of these game mechanics, design, and technological features should be guided by the scientific foundations established in stage 1. It is imperative to translate the theoretical basis into relevant, implementable game design elements. This stage therefore aims to answer the following 3 questions: (1) Which game mechanics are best suited to achieve the intended outcome objectives? (2) What are the design requirements? and (3) How can the game design best accommodate the evaluative trial?

Which Game Mechanics Are Best Suited to Achieve the Intended Outcome Objectives?

Game mechanics are rules or methods that define the interactions and flow of a game session. They describe interactions, game conditions, and triggers in an abstract manner. The most frequently employed game mechanics in electronic health are currently rewards and feedback [44], but other examples include turn-taking, story, penalties, realism, and protégé effect. In the past, game developers often decided upon a game genre before selecting what game mechanics to use. However, as game mechanics are more instrumental toward achieving the intended outcome objectives, developers should first work together with relevant subject matter experts to map the outcome objectives, models, and theories identified in stage 1 onto relevant game mechanics before settling on a particular game genre [44]. In mapping the scientific foundations onto these mechanics, developers gain insight into which game mechanics should be used to effectively achieve the intended outcomes. Although this is a relatively novel approach, there are currently several well-documented examples in the research literature of how this can be done for SGH that have a pedagogical or behavioral focus [45,62,63]. These types of SGH often have outcome objectives that pertain to either *understanding* or the acquisition of a specific skill set (eg, communication skills and coping skills). Depending on the type of outcome envisaged, there may be layers of intermediate learning objectives that need to be addressed. Here, the pedagogical or behavioral intents should be mapped to a low-level game mechanic implementation. In 2015, Arnab proposed a model for translating learning objectives into learning mechanics and mapping these to relevant game mechanics [45]. This so-called learning mechanics-game mechanics model guides developers in the development of more effective, pedagogy-driven SGH, as it ensures that game mechanics are chosen on the basis of their ability to contribute toward the intended outcomes. In the example of reducing peri-operative pain, stress, and anxiety in children, one such learning objective may include remembering the sequence of events for the upcoming procedure (knowing what to expect and do). This involves the thinking skills *understanding* and *retention*. Several learning mechanics address these thinking skills: *exploration*, *repetition*, and *planning*. Each of these learning mechanics can in turn be mapped onto one or more game mechanics, for example, *story*, *cascading information*, and *strategy and planning*. As such, the scientific foundations established in stage 1 can be translated into the game construct.

What Are the Design Requirements?

At this point, the target audience profile needs to be broadened to guide the design choices. Although the specifics will depend on the objective and scope of SGH, the objective is to gain insight into (1) the context of use and (2) the reality of the target audience. What context will the tool be used in? Will there be access to special equipment or technical support? Will the tool be used at home or in hospital? How realistic does the tool need to be (level of fidelity and immersion)? If it needs to be realistic, what characters does the target audience meet or interact with? What type of environments do they move about in? What situations or dilemmas do they typically encounter? In addition, information regarding optimal user experience for the target audience should be collected. This includes computer literacy skill levels, literacy and numeracy levels, and possible physical or mental limitations that may pose restrictions on game design (eg, epilepsy, auditory problems, and limited motor function). This type of information can be gathered through interviews, time-and-motion exercises (shadowing a typical user for a day), or focus groups with the target audience or relevant experts.

How Can the Game Design Best Accommodate the Evaluative Trial?

Are there any design considerations with respect to the future evaluation of the SGH? For instance, if data need to be collected, should this data collection be included in the game design? (eg, tracking user response time, motion ranges) Will it be collected out with the game format (eg, pre and postgame interviews, clinical scales, and biologic sampling). Does it require live feedback or investigator intervention during game play? Are there any design considerations for use in a clinical environment? Should the game design include components that can help track or assess user experience (eg, level of immersive play, eye tracking, etc)?

Stage 3: Game Development

Once stage 2 has been completed, developers should have sufficient scientifically grounded input to guide the practical development of the game. Various approaches can be used depending on the complexity, the developer's resources, and software and technological skills, but overall, the process comprises the selection and development of the (1) game genre, (2) game rules, (3) content, and (4) visuals and user interface. This stage ideally occurs in an iterative, participatory manner, involving key stakeholders such as clinical experts and target users to informally test and refine the tool along the way.

Game Genre

The scientific and design foundations developed in stages 1 and 2 should now enable developers to select the most appropriate interface genre (eg, first person, third person, and isometric) and procedure genre (eg, strategy game, adventure game, and shooter game) for the intended target audience and context of use. The genre chosen should facilitate the incorporation of the game mechanics and design requirements identified under stage 2.

Game Authoring Tool

There are several authoring tools available for game development, and it is important to assess upfront which authoring tool is most suitable for the project. This will largely depend not only on the technical capabilities available in the team (eg, team members with specific coding skills) but also on whether future administrators of the SGH will need to make their own modifications, such as adding new narratives or including new data measurements. Considerations should be given to open-source authoring tools versus licensed authoring platforms.

Game Rules

Developers can now draw up a set of game rules that specifies how the player's actions impact the game environment. Depending on the intended purpose of the tool, these rules may need to be consistent and transparent (to allow players to strategize on the basis of their knowledge of the rules) or hidden or unpredictable (to force players to truly reflect on their choices rather than making decisions that help raise game scores). Such rules are often described in mathematical algorithms that govern the tool's programming. When the SGH need to closely reflect reality to achieve the intended outcome objectives, for instance, through use of realistic narratives or life-like responses to in-game decision making, developers will need to translate the relations, hierarchies, impacts, and relative weights of importance of the outcome determinants, identified in stage 1, into a mathematical algorithm. This will facilitate procedurally generated narrative branching and can drive feedback and reward approaches. To stimulate flow and user engagement, developers can also build in rules that adapt game difficulty and other game-play elements to the performance or physical or mental state of the user.

Game Content

The amount of content required in a game will vary substantially depending on the intended objectives. Many SGH require at least some instructional content or a narrative that ties everything together. When SGH have a large pedagogical or behavioral focus, the narratives can become more elaborate, ranging from linear stories to nonlinear stories that have branching and even offer multiple endings. Within the context of health, narratives are a valuable resource to generate an understanding of the impact of an illness on the patient's life and well-being [91,92]. Narratives are an everyday medium that people use to communicate information to one another, and therefore they are a familiar format to users [93]. Narratives are perceived as providing essential emotional and social information not usually found within routine resources that lend meaning and perspective to a patient's predicament [94].

Developers should develop the game content in function of the intended outcomes. Linear story lines may be less time consuming, but they also tend to reduce the potential efficacy of the narrative as a persuasive mechanism as it is not responsive to the users, their state, or in-game decisions. Many SGH are designed using a one-size-fits-all approach; however, recent research shows that this approach may not be effective as different types of people are motivated by different persuasive strategies [95], and a strategy that worked well with one group of people may actually demotivate a different group [95,96]. Personalization has also been shown to be important for successful impact [97]. The relevance of SGH is often directly related to their ability to capture the patient's unique reality and circumstances in the content [93,98]. In addition, features that allow patients to self-personalize content may promote autonomy and empower patients to take ownership over health care decisions [99]. Developers should also address (health) literacy and numeracy profiles of the intended target audience to maximize chances of success [100-104]. Therefore, building on the target audience profile and design requirements identified in stage 2 allows developers to take a more informed approach toward game content.

Game Visuals and User Interface

On the basis of the specific target audience and design requirements, a theme needs to be chosen, which specifies the overall look and feel of the tool (colors, sounds, environments, characters, navigation, interface, etc). At the same time, developers will need to assess what level of visual conceptualization will be needed. In some cases, the use of archetypical symbols or icons may be warranted to convey complex concepts either to avoid information overload or to eliminate bias [101,105,106]. Graphics have also shown to impact the emotional response of participants [107].

Stage 4: Game Evaluation

The game has now been developed, informally tested, and refined with users, and it should be ready for (clinical) evaluation. Once the trial sites and investigators have been chosen, ethical committee or other approvals have been granted, and users have been recruited for the evaluation study, developers can commence the evaluation, analysis, and assessment of whether the tool successfully achieves the intended outcomes. This stage ideally occurs in consultation with relevant research experts who can guide and oversee the evaluation studies and support the analysis of collected data.

Stage 5: Implementation

On the basis of the findings of stage 4, developers may wish to further refine and reevaluate updated versions of the tool or proceed immediately with rollout toward the intended target audience. Regardless of the outcomes of the game evaluation studies, developers should try to disseminate the study findings to the wider SGH research community, as this will help further advance the field. Even publishing and communicating null results may provide insight on how to optimize SGH interventions and provide guidance on the best practices and pitfalls to avoid. If a game is successfully validated and implemented or marketed for the intended target audience, efforts should be made to collect user data in the field, to help monitor for adverse events (if relevant), or to further explore the validity and use of the SGH.

Stakeholders

More research should be done to identify which stakeholders should be involved in the design process, to understand how to engage them, and at what stage of the development. We propose to consider at least the following 4 stakeholders.

Subject Matter Expert

At the earliest stage of development, subject matter experts are well placed to provide input and guidance on the 4 questions that should be answered when establishing the scientific foundations.

Target Audience

When deciding on the level of user involvement, one should balance the need for input from users with the availability of resources such as time and funding [32]. One should only involve end users at relevant stages of development. We propose to engage them at specific points in stages 2, 3, and 4, when their input and participation are most likely to yield valuable, accurate information and feedback. At stage 2, end users should be engaged to broaden the profile research and identify their specific design requirements that are crucial to tool effectiveness (ie, not esthetic design perspectives). The purpose of the contact is to determine in more detail who the end users are, which subgroups exist, what their socioeconomic backgrounds are, their day-to-day reality, and other aspects that may inform game design, such as literacy levels, numeracy levels, computer skills, and understanding of subject matter. Many established formats to engage end users are available to developers. Examples include time and motion exercises in which developers shadow end users during a typical day in their life or during a relevant event, such as a hospitalization.

At stage 3, end users should be actively engaged in the testing of early prototypes of the game to gather feedback on such aspects as user experience, content relevance, realism, graphic design features (minimal), and preliminary assessment of the achievability of outcome objectives. It is important to note here that not all user feedback needs to be incorporated. To avoid *feature creep* and ensure effective use of project resources, subject matter experts can help evaluate which feedback should be prioritized. Ideally, an emphasis is placed on feedback that will help enhance user uptake and SGH effectiveness.

At stage 4, end users should be recruited into a quality trial to validate the game. End users who participate in trials should not be involved in the earlier stages of the development.

(Clinical) Research Expert

Research experts should be engaged to advise on scientific approach and trial design at an early stage of development and ideally during the trial.

Business Expert

To ensure market readiness and effectively implement and roll out the SGH to the market, a business expert should be consulted, ideally no later than stage 3.

Aside from these 4 stakeholders, it may be relevant to consult with regulators, health care professionals, patient organizations, health technology assessments, and others throughout the various stages of the development process.

Working with multiple stakeholders carries a specific set of challenges such as clear alignment on roles and responsibilities, finding a common language, understanding of limitations, and consensus on priorities and outcomes [30,55]. These may be overcome, at least in part by (1) educating stakeholders about the development process and the tools and methods used, by means of interactive, hands-on workshops, (2) forming an advisory board of key stakeholders which meets on a regular basis to discuss the project, and (3) by assigning a project manager who functions as the go-to person for all stakeholders involved and who can make final judgment calls in case of conflict, in line with the project's intended objectives and within the stipulated resource limitations.

Discussion

A review of existing literature, recommendations, and guidelines on SGH development has allowed us to formulate a framework for developing theory-driven, evidence-based SGH that represents many of the requirements set out by SGH stakeholders in the research literature. The framework covers all aspects of the development process (scientific, technological, and design) and is transparently described in sufficient detail to allow developers to implement it in a wide variety of projects, irrespective of discipline, health care segments, or focus. Adoption of such a consensus framework by the wider SGH research community is a first step toward increasing probability of success and raising the quality of SGH by providing the necessary evidence required by stakeholders. Moreover, it would also enhance the credibility of SGH developers and allow them to achieve a sustainable market share.

Conflicts of Interest

SV is a paid consultant of MindBytes BVBA, CB is an employee of MindLab Interactive AI Inc and previously served as a paid consultant of MindBytes BVBA, and GVS is the owner of MindBytes BVBA and MindLab Interactive AI Inc.

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Abbreviations

RCT: randomized controlled trial
SGH: serious games for health

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Original Paper

An Interactive Mobile App Game to Address Aggression (RegnaTales): Pilot Quantitative Study

Jeffrey G Ong[1], MPsych; Nikki S Lim-Ashworth[1], DClinPsy; Yoon P Ooi[1,2], PhD; Jillian S Boon[1], MA; Rebecca P Ang[3], PhD; Dion H Goh[4], PhD; Say H Ong[1], MMed; Daniel S Fung[1], MMed

[1]Department of Developmental Psychiatry, Institute of Mental Health, Singapore, Singapore

[2]Department of Psychology, University of Basel, Basel, Switzerland

[3]Psychological Studies, National Institute of Education, Nanyang Technological University, Singapore, Singapore

[4]Wee Kim Wee School of Communication and Information, Nanyang Technological University, Singapore, Singapore

Corresponding Author:
Jeffrey G Ong, MPsych
Department of Developmental Psychiatry
Institute of Mental Health
Health Promotion Board Building
3 Second Hospital Avenue #03-01
Singapore, 168937
Singapore
Phone: 65 64353251
Fax: 65 64385349
Email: jeffrey_gx_ong@imh.com.sg

Abstract

Background: The rapid advancement in media technology has radically changed the way we learn and interact with one another. Games, with their engaging and interactive approach, hold promise in the delivery of knowledge and building of skills. This has potential in child and adolescent mental health work, where the lack of insight and motivation for therapy are major barriers to treatment. However, research on the use of serious games in mental health interventions for children and adolescents is still in its infancy.

Objective: This study adds to the research on serious games in mental health interventions through the development and evaluation of RegnaTales, a series of 6 mobile apps designed to help children and adolescents manage anger. We examined the usability and playability of RegnaTales, as well as children's aggression levels before and after the game play.

Methods: A total of 72 children aged between 6 and 12 years were recruited for the study. Thirty-five participants had a clinical diagnosis of disruptive behavior disorders (DBD), whereas 37 were typically developing (TD) children. Each child played 1 of the 6 RegnaTales apps for approximately 50 min before completing the Playability and Usability Questionnaire. The Reactive-Proactive Aggression Questionnaire was completed before and after the game play.

Results: The overall results showed high levels of enjoyment and playability. TD children and children with DBD had similar experienced fun and perceived playability scores on all 6 mobile apps. All 6 mobile apps garnered comparable experienced fun and perceived playability scores. Furthermore, 42% (5/12) to 67% (8/12) of the children indicated that they would like to play the games again. Importantly, children felt that they acquired skills in anger management, were motivated to use them in their daily lives, and felt confident that the skills would help them better manage their anger. Children reported significantly lower reactive aggression after playing the mobile apps Rage Raver (*P*=.001), Abaddon (*P*=.008), and RegnaTools (*P*=.03). These apps focused on the psychoeducation of the link between thoughts and emotions, as well as equipping the participants with various emotion regulation strategies such as relaxation and cognitive restructuring.

Conclusions: This study presents evidence to support RegnaTales as a feasible serious game. The preliminary findings associated with reduction in reactive aggression, coupled with future research to further establish its efficacy, could warrant RegnaTales as a potential intervention for anger issues among clinical and community populations.

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KEYWORDS

video games; mental health; anger management; mobile app

Introduction

Background

Anger issues are among one of the most frequent reasons for referral to intervention within the developmental population [1]. A significant number of childhood mental health problems, particularly attention-deficit/hyperactivity disorder (ADHD; prevalence of 5%), conduct disorder (CD; prevalence of 4%), and oppositional defiant disorder (ODD; prevalence of 3.3%), have features associated with anger, including irritability and aggression toward others [2]. Evidence suggests that distorted thinking patterns often cause psychosocial interactions to be appraised in a maladaptive manner, triggering anger, aggression, and disruptive behavior [3,4]. To address these cognitive biases, treatment needs to support children in restructuring existing unhelpful thought patterns and equip them with more adaptive response strategies [5].

Cognitive behavioral therapy (CBT) is an approach centered on the conceptual principles outlined above. It has been shown to be efficacious in the treatment of childhood anger problems [6,7]. However, CBT is typically administered through individual and group formats, which could be time-consuming and resource-intensive. Furthermore, parents are often required to accompany the child to see the therapist and this limits the accessibility of treatment [8,9]. Finally, children referred for anger management may not have insight and motivation for change, which are additional barriers for therapy [10]. With advancements in technology, there have been attempts to increase access to therapy through alternatives or adjuncts (eg, computers, internet, and mobile phones) to clinic-based therapy [11-18]. CBT, in particular, is well suited for such adaptations because of its structured and systematic format. A review of the literature indicated that where proven techniques are adapted for computer delivery, clinical outcomes are comparable with traditional face-to-face services [19,20].

Serious Games Using Cognitive Behavioral Therapy Principles

Games hold promise in building skills and imparting knowledge to children as they find the interactive features, simulations, and immersive environments both enticing and engaging [21]. The game world is known to be a *safe* environment to practice behaviors in role-play situations through rule learning and repetition of tasks [22], and it has been demonstrated that games can improve skills in areas such as communication and problem-solving [23]. The use of games for learning, teaching, and psychological interventions is gaining attention. Serious games are defined as *entertaining games with non-entertainment goals* [24], and such games have adopted the CBT approach to address behavioral and emotional problems in children and adolescents [25,26].

RegnaTales

RegnaTales, a series of 6 mobile apps, was created in response to the above advantages of using mobile technology and serious games to increase access to treatment and enhance the motivation of children to learn skills [27,28]. RegnaTales was developed from the Social Problem-Solving Skills Training (SPSST) for anger management [29], based on a cognitive behavioral framework. The SPSST was originally administered in a face-to-face therapy setting through a workbook. It was subsequently developed into a Web-based social problem-solving game, Socialdrome [30] and evolved into the current interactive role-playing game–based mobile apps—RegnaTales. See Multimedia Appendix 1 for screenshots of the RegnaTales mobile apps.

The first 4 mobile apps are game-based apps that teach various anger management strategies, whereas the fifth and sixth apps focus on helping the children apply these skills in their daily lives. The content of each mobile app is listed in Table 1.

Table 1. List of RegnaTales apps.

RegnaTales apps	Objectives
Game-based mobile apps	
Village of Lost Expressions	Learn to identify different feelings
Rage Raver	Learn to distinguish between positive and negative thoughts; learn to identify bodily signs of anger; learn to replace negative thoughts with positive thoughts; learn deep breathing; learn guided imagery
The Illusionist	Learn perspective taking; use of cognitive restructuring techniques; use of deep breathing; use of guided imagery; exposure to a variety of leisure activities to cope with anger
Abaddon	Fighting fair; being firm; use of perspective taking; use of cognitive restructuring techniques; use of deep breathing; use of guided imagery; use of leisure activities to cope with anger
Therapeutic tools	
RegnaTools	Anger coping skills
TimeOut!	Daily monitoring of feelings and intensity; increase awareness of physiological symptoms; log of triggering events; trigger use of anger coping strategies when angry; feedback on the frequency of each feelings throughout the week; monitor use of anger coping strategies

In a pilot evaluation of the first RegnaTales mobile game app by Ooi et al [31] conducted in Switzerland, the children found the game highly playable and enjoyable. However, this evaluation was limited in scope because only 1 of the apps was utilized, the number of participants was small, and it was done with a nonclinical population.

The aim of this study was to evaluate RegnaTales in the context of the apps' usability and playability across domains, including experienced fun, perceived playability, understanding of goals, and perceived impact. In addition, our study explored whether RegnaTales helped in attenuating aggression.

Methods

Recruitment

Recruitment took place from November 2015 to December 2017. Participants with a disruptive behavior disorders (DBD) diagnosis were recruited from a psychiatric outpatient clinic in Singapore. According to the Diagnostic and Statistical Manual of Mental Disorders, fourth edition, text revision [32], DBD is a cluster of childhood mental health diagnoses that includes ADHD, ODD, and CD. Flyers were put up in the community to recruit children who have a typically developing (TD) profile.

A total of 72 children aged between 6 and 12 years, comprising those with a clinical diagnosis of DBD and those who were TD, participated in the study. A total of 68 children with DBD were referred for the study by their psychiatrists, of which 35 agreed to participate. The majority of these participants were diagnosed with ADHD only (n=33), whereas 1 had a comorbid diagnosis of ODD and ADHD, and the remaining participant had a diagnosis of CD and ADHD. Another 37 children with a TD profile responded to flyers put up in the community and were recruited for the study. The study was approved by the Domain Specific Review Board (DSRB) of the National Healthcare Group (DSRB 2015/00986). Written informed consent and assent were obtained from the child participants and their parents before commencement of the study procedures.

Procedure

The 6 RegnaTales apps were developed sequentially, with each app taking about 4 months to develop. Upon completing the development of each app, 12 child participants were recruited to test the app. We tried to recruit an equal number of TD children and children with DBD to test each app. Each RegnaTales app was tested by a different group of 12 child participants. The children played the assigned RegnaTales app on an Apple iPad (9.7-inch screen size) for approximately 50 min before completing the Playability and Usability Questionnaire (PUQ) [31]. They also completed the Reactive-Proactive Aggression Questionnaire [33] before and after the game play. The aggression scores of 2 children using the Abaddon mobile app were not captured because of a technical problem during the research study (ie, data were not captured by the server). The same procedure was followed for each RegnaTales app. Each participant was reimbursed Singapore Dollar $30 at the end of the visit.

Technical Details

RegnaTales was developed using the Corona development platform for mobile apps with the back end running PHP and a MySQL database on a Microsoft Windows Server. RegnaTales has the capability of being ported to various mobile operating systems and devices. Character animation and user interaction were accomplished using Kwik, an Adobe Photoshop plugin. RegnaTales is delivered using the English language.

Measures

Playability and Usability Questionnaire

Similar to the study by Ooi et al [31], elements of the gaming experience such as fun, game experience, willingness to continue playing, and curiosity were measured using the following 4 domains from the extended Short Feedback Questionnaire (eSFQ) [34]:

- Experienced fun: This was measured using a 5-point rating scale, where 1=*yawn, boring* and 5=*yeah, fun*
- Game experience: This was assessed by getting children to mark predefined attributes (ie, *simple*, *difficult*, *great*, *childish*, *fun*, *boring*, *exciting*, *tiring*, *intuitive* and *confusing*)
- Willingness to continue using the game: This was assessed using the question *Would you like to play the game again?* answered with *yes*, *maybe*, or *no*
- Curiosity: This was measured with 2 items on a 5-point Likert scale where 1=*completely disagree* to 5=*completely agree*

In addition to the above items from the eSFQ, the PUQ included the following 2 domains to further understand the experience and understanding of the children:

- Perceived playability: Perceived playability of the mobile apps was measured using 9 items from Tan et al [35] (5-point Likert scale where 1=*completely disagree* to 5=*completely agree*)
- Understanding of the goals of the game (6 multiple choice options)

As mobile apps 5 and 6 are nongame-based and are focused on the application of skills, some irrelevant items (eg, whether they liked the story and what they thought were the goals of the games) were removed and an additional domain to assess the knowledge, attitudes, and intentions related to the target behavior of anger management was added. This is a modification of 5 items based on the user version of the Mobile Application Rating Scale [36]:

- Perceived impact (5 items, 5-point Likert scale where 1=*completely disagree* to 5=*completely agree*).

Reactive-Proactive Aggression Questionnaire

This is a brief self-report scale that comprises 23 items measuring reactive (11 items, Cronbach alpha=.83) and proactive (12 items, Cronbach alpha=.82) aggression among children and yields an overall score of aggression. Items are rated on a 3-point Likert scale (0=*never*, 1=*sometimes*, and 2=*often*). The Reactive-Proactive Aggression Questionnaire

(RPQ) has been validated extensively for use with the developmental population in reporting aggression and has been shown to have robust psychometric properties [37,38].

Data Analysis

Independent sample *t* tests (2-tailed) were used to compare the aggression levels of children with DBD with that of TD children, before using the mobile apps. To understand the participants' experience of RegnaTales, descriptive statistics were used to present the playability and usability feedback. Mann-Whitney tests (2-tailed) were conducted to examine the differences between children with DBD and TD children in terms of age, playability, and usability scores. Kruskal-Wallis *H* tests were conducted to examine if there were differences in playability and usability scores among the mobile apps. In addition, Wilcoxon signed rank tests (2-tailed) were conducted to examine if there were changes in aggression after game play. All statistical significance levels were determined at $P<.05$.

Results

Overview

There was a total of 23 female and 49 male participants, aged between 6 and 12 years, with a mean age of 8.79 (SD 1.73) years. Table 2 presents the demographics of the participants for each of the 6 mobile apps. Mann-Whitney tests showed that there were no significant differences in the ages of children in the DBD group and children in the TD group across all 6 mobile apps.

Table 3 shows the RPQ scores of TD children and children with DBD before game play. Independent sample *t* tests showed that children with DBD had higher reactive aggression, with $t_{70}=-2.60$ and $P=.01$; proactive aggression, with $t_{70}=-3.58$ and $P=.001$; and overall aggression, with $t_{70}=-3.53$ and $P=.001$, on the RPQ as compared with TD children before using the mobile apps.

Experienced Fun

As shown in Table 4, experienced fun scores ranged from 4.17 (Rage Raver) to 4.67 (RegnaTools). A Kruskal-Wallis *H* test showed that there were no significant differences in the experienced fun scores across the 6 mobile apps, with $\chi^2_5=0.5$ and $P=.99$. Mann-Whitney tests indicated that there were no significant differences in the experienced fun scores between TD children and children with DBD in each of the 6 mobile apps (see Table 4).

Game Experience

To better understand the participants' experience of the mobile apps, we looked at the attributes selected by the participants in describing their experience when using each of the 6 mobile apps (Figures 1 and 2).

Generally, half or more participants found the mobile apps *exciting*, *fun*, and *great*. However, less than one-third of them found the apps *intuitive* and *simple*.

Figure 2 shows that the mobile apps differed vastly in their difficulty levels. For Village of Lost Expressions and The Illusionist, more than half of the participants found the tasks difficult. However, on the other 4 mobile apps, most participants did not find the tasks difficult.

Continued Usage

Figure 3 shows the participants' responses when asked if they would like to play the various mobile apps again.

With the exception of Rage Raver, all participants indicated either *yes* or *maybe*, when asked if they would like to play the apps again and none of the participants indicated *no*.

Curiosity

As shown in Table 5, curiosity scores ranged from 4.04 (Rage Raver) to 4.54 (The Illusionist). A Kruskal-Wallis *H* test showed that there were no significant differences in the curiosity scores among the 4 mobile game apps, with $\chi^2_3=2.4$ and $P=.51$. Overall, 38 out of 48 (79%) participants indicated that they wanted to see more of the game world, whereas 41 out of 48 (86%) indicated that they were curious to see what would happen next in the game. Mann-Whitney tests indicated that there were no significant differences in the curiosity scores between TD children and children with DBD in each of the 4 mobile game apps (see Table 5).

Perceived Playability

As shown in Table 6, perceived playability scores ranged from 3.91 (Rage Raver) to 4.33 (The Illusionist). A Kruskal-Wallis *H* test showed that there were no significant differences in the perceived playability scores among the 6 mobile apps, with $\chi^2_5=6.3$ and $P=.28$. Mann-Whitney tests indicated that there were no significant differences in the perceived playability scores between TD children and children with DBD in each of the 6 mobile apps, as shown in Table 6.

As shown in Figure 4, more than 50% (6/12) of children agreed/strongly agreed that RegnaTales had good playability features on all domains, with the exception of *can play without help*, where 33% (4/12) to 58% (7/12) agreed/strongly agreed.

Understanding of the Goals of the Game

The children indicated the goals of the game apps as the following: save the hero's parents (39 out of 48, 81%), make friends (19 out of 48, 40%), gain more points and power (21 out of 48, 44%), learn to recognize other's feelings (34 out of 48, 71%), and learn more about themselves (28 out of 48, 58%).

Perceived Impact

As shown in Table 7, perceived impact score was 4.40 for RegnaTools and 4.45 for TimeOut!. Mann-Whitney tests indicated that there were no significant differences in the perceived impact scores between children who used RegnaTools and TimeOut!, with $U=64.0$ and $P=.66$.

Table 2. Demographics of participants for each mobile app.

Demographics	Typically developing (n=6)	Disruptive behavior disorder (n=6)	Total sample (n=12)
Village of Lost Expressions			
Gender, n			
Female	1	1	2
Male	5	5	10
Age (years), mean (SD)	8.17 (1.72)	8.5 (1.52)	8.33 (1.56)
Rage Raver			
Gender, n			
Female	2	2	4
Male	4	4	8
Age (years), mean (SD)	8.67 (2.16)	10 (1.67)	9.33 (1.97)
The Illusionist[a]			
Gender, n			
Female	5	0	5
Male	2	5	7
Age (years), mean (SD)	8.29 (1.6)	9 (1.41)	8.58 (1.51)
Abaddon			
Gender, n			
Female	3	0	3
Male	3	6	9
Age (years), mean (SD)	8 (2.28)	9 (1.21)	9.17 (2.12)
RegnaTools			
Gender, n			
Female	3	0	3
Male	3	6	9
Age (years), mean (SD)	8.33 (1.97)	9.33 (1.37)	8.83 (1.7)
TimeOut!			
Gender, n			
Female	6	0	6
Male	0	6	6
Age (years), mean (SD)	8.33 (1.86)	8.67 (1.37)	8.5 (1.57)

[a]Typically developing (n=7); disruptive behavior disorder (n=5).

Table 3. Overall Reactive-Proactive Aggression Questionnaire scores before game play.

Category	Reactive aggression, mean (SD)	Proactive aggression, mean (SD)	Overall aggression, mean (SD)
Typically developing	0.68 (0.38)	0.11 (0.18)	0.38 (0.24)
Disruptive behavior disorder	0.92 (0.39)	0.32 (0.32)	0.61 (0.30)

Table 4. Experienced fun scores.

App name and participant category	Mean (SD)	*U* value	*P* value
Village of Lost Expressions		15	.99
Typically developing (n=6)	4.67 (0.82)		
Disruptive behavior disorder (n=6)	4.33 (1.03)		
Total sample (n=12)	4.50 (0.90)		
Rage Raver		9	.18
Typically developing (n=6)	5 (0)		
Disruptive behavior disorder (n=6)	3.33 (1.97)		
Total sample (n=12)	4.17 (1.59)		
The Illusionist		13	.52
Typically developing (n=7)	4.71 (0.76)		
Disruptive behavior disorder (n=5)	4.20 (1.10)		
Total sample (n=12)	4.50 (0.90)		
Abaddon		14.5	.73
Typically developing (n=6)	4.67 (0.82)		
Disruptive behavior disorder (n=6)	4.00 (1.67)		
Total sample (n=12)	4.33 (1.3)		
RegnaTools		18	.99
Typically developing (n=6)	4.67 (0.82)		
Disruptive behavior disorder (n=6)	4.67 (0.82)		
Total sample (n=12)	4.67 (0.78)		
TimeOut!		15	.99
Typically developing (n=6)	4.33 (1.03)		
Disruptive behavior disorder (n=6)	4.67 (0.82)		
Total sample (n=12)	4.50 (0.90)		

Figure 1. Positive attributes of the RegnaTales mobile apps.

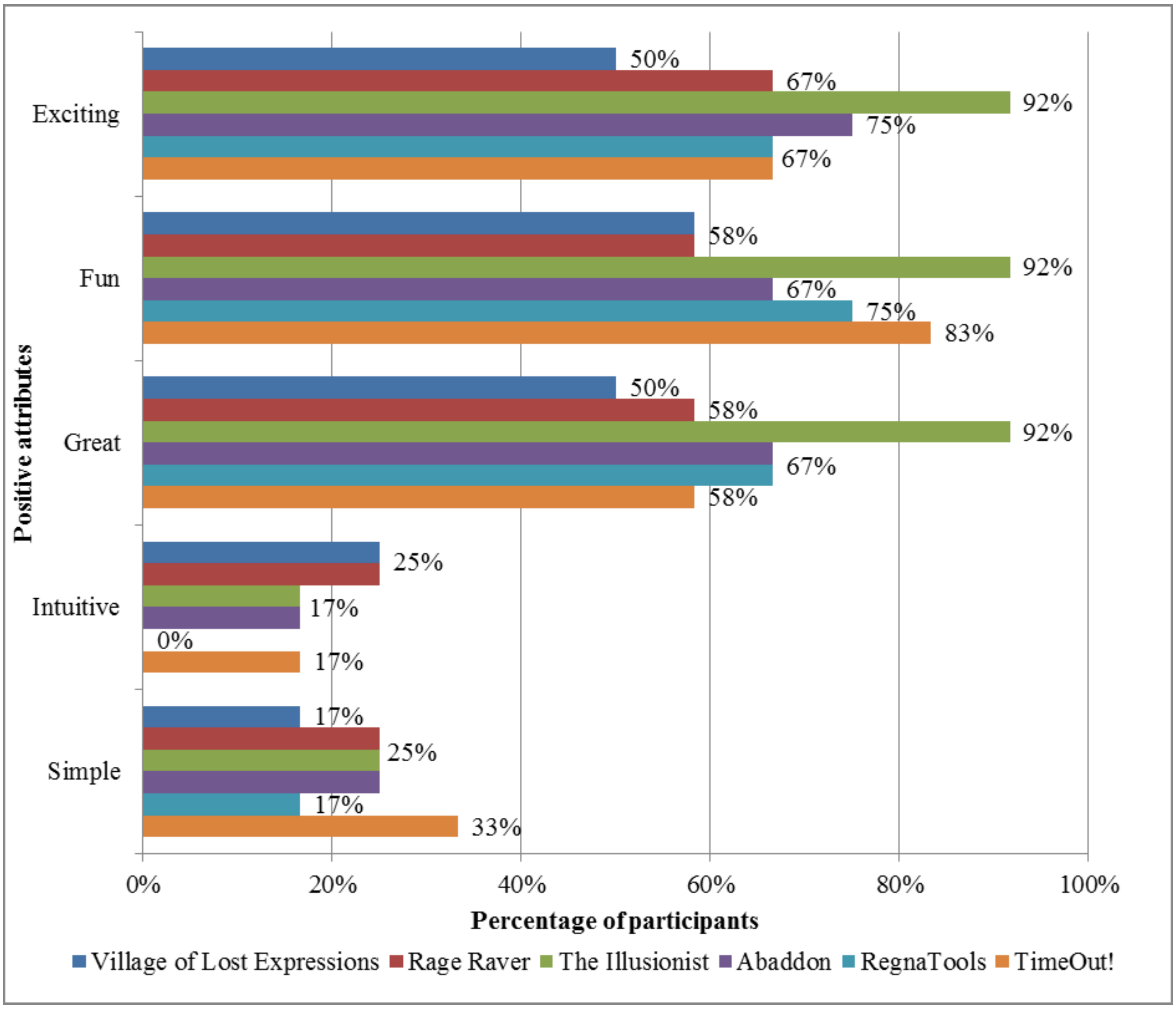

Figure 2. Negative attributes of the RegnaTales mobile apps.

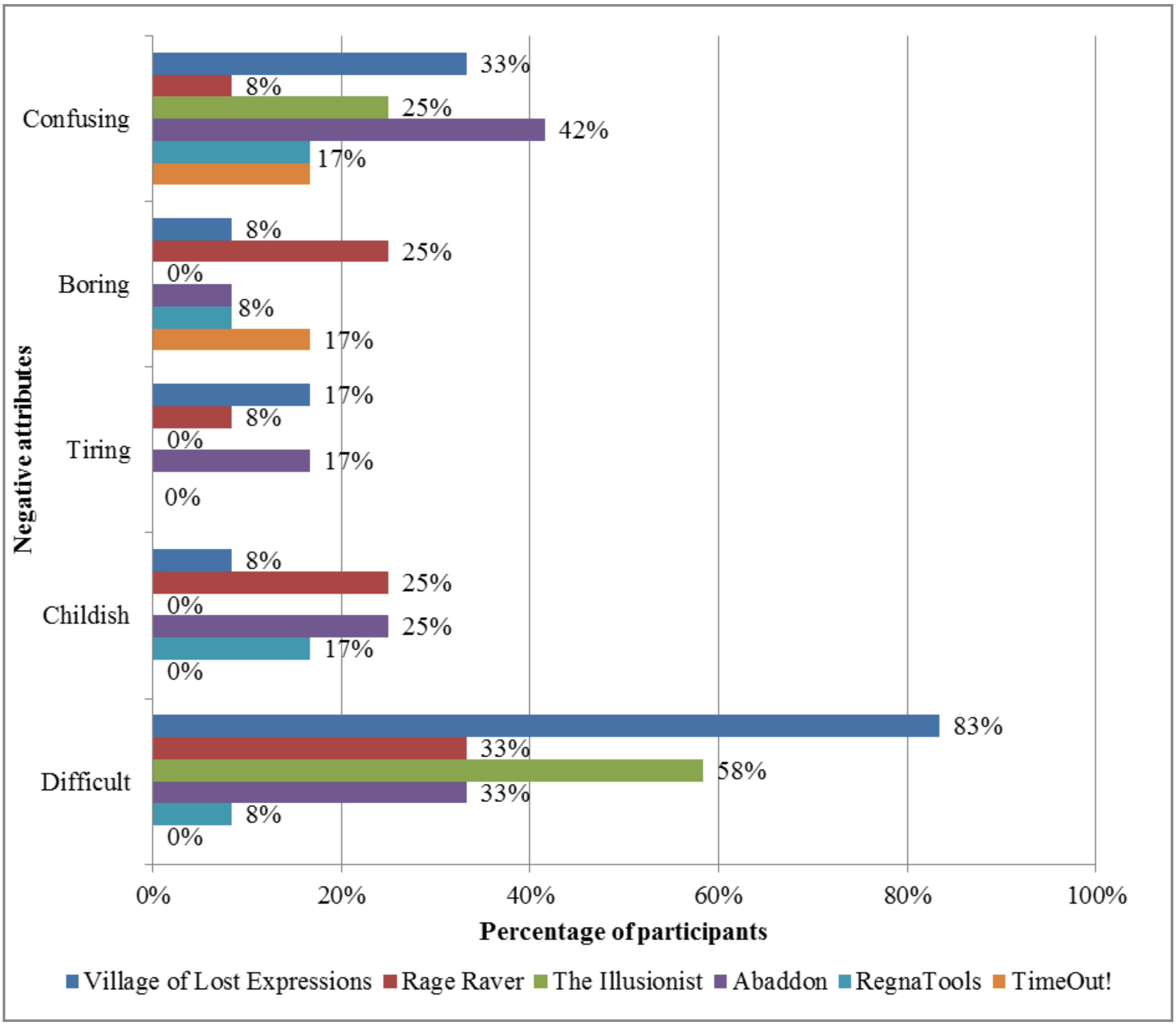

Figure 3. Continued usage for mobile apps.

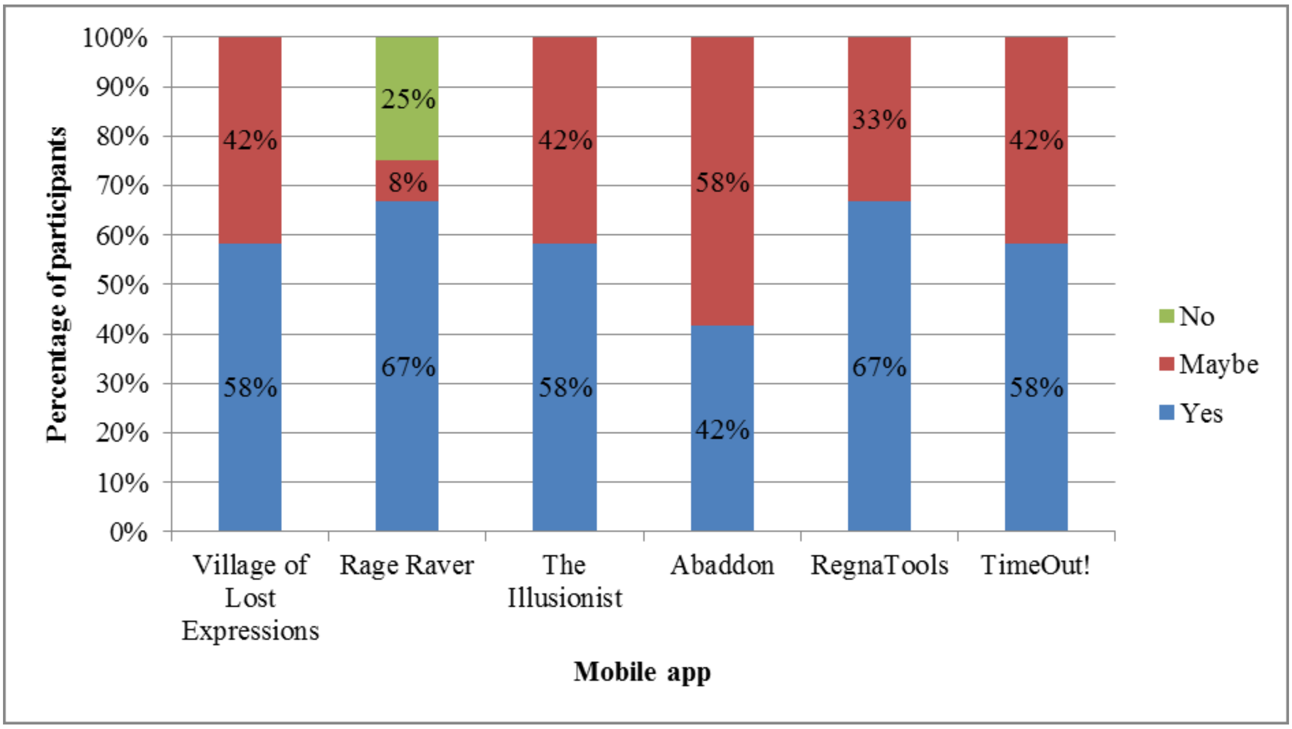

Table 5. Curiosity scores.

App name and participant category	Mean (SD)	*U* value	*P* value
Village of Lost Expressions		16	.87
Typically developing (n=6)	4.25 (0.88)		
Disruptive behavior disorder (n=6)	4.42 (0.66)		
Total sample (n=12)	4.33 (0.75)		
Rage Raver		15.5	.99
Typically developing (n=6)	4.33 (1.63)		
Disruptive behavior disorder (n=6)	3.75 (1.94)		
Total sample (n=12)	4.04 (1.74)		
The Illusionist		11	.41
Typically developing (n=7)	4.86 (0.24)		
Disruptive behavior disorder (n=5)	4.10 (1.47)		
Total sample (n=12)	4.54 (0.99)		
Abaddon		10	.17
Typically developing (n=6)	4.33 (1.21)		
Disruptive behavior disorder (n=6)	4.17 (0.41)		
Total sample (n=12)	4.25 (0.87)		

Table 6. Perceived playability scores.

App name and participant category	Mean (SD)	*U* value	*P* value
Village of Lost Expressions		14.5	.62
Typically developing (n=6)	3.89 (0.53)		
Disruptive behavior disorder (n=6)	4.00 (0.72)		
Total sample (n=12)	3.94 (0.60)		
Rage Raver		17	.92
Typically developing (n=6)	3.94 (0.97)		
Disruptive behavior disorder (n=6)	3.87 (1.11)		
Total sample (n=12)	3.91 (0.99)		
The Illusionist		13.5	.56
Typically developing (n=7)	4.54 (0.35)		
Disruptive behavior disorder (n=5)	4.04 (1.09)		
Total sample (n=12)	4.33 (0.75)		
Abaddon		12.5	.42
Typically developing (n=6)	4.13 (0.63)		
Disruptive behavior disorder (n=6)	3.85 (0.45)		
Total sample (n=12)	3.99 (0.54)		
RegnaTools		9.5	.20
Typically developing (n=6)	4.08 (0.62)		
Disruptive behavior disorder (n=6)	4.54 (0.45)		
Total sample (n=12)	4.31 (0.57)		
TimeOut!		17.5	.94
Typically developing (n=6)	4.31 (0.45)		
Disruptive behavior disorder (n=6)	4.33 (0.66)		
Total sample (n=12)	4.32 (0.54)		

Out of the 24 children who used mobile apps 5 and 6, 19 (79%) agreed/strongly agreed that they were more aware of themselves and their feelings, 23 (96%) agreed/strongly agreed that they had learnt skills to manage their anger, 22 (92%) agreed/strongly agreed that they wanted to learn more skills to manage their anger, 18 (75%) agreed/strongly agreed that they were motivated to use the skills learnt in the mobile apps in their daily lives, and 21 (88%) agreed/strongly agreed that the use of the mobile apps will help them manage their anger. Mann-Whitney tests indicated that there were no significant differences between the TD children and children with DBD in the perceived impact scores for mobile app 5 (RegnaTools), with U=14.5 and P=.62, and mobile app 6 (TimeOut!), with U=16.0 and P=.81.

Aggression Levels

Wilcoxon signed rank tests indicated that children reported significantly lower reactive aggression after playing the mobile apps Rage Raver, with Z=−2.95 and P=.001; Abaddon, with Z=−2.52 and P=.008; and RegnaTools, with Z=−2.16 and P=.03. Children reported significantly lower overall aggression after playing the mobile apps Abaddon, with Z=−2.52 and P=.008 and RegnaTools, with Z=−2.14 and P=.03. There were no significant changes in proactive aggression in the children after the use of the mobile apps. The results are summarized in Table 8.

To understand if the use of the mobile apps affected the aggression scores of children with DBD differently from TD children, we analyzed the RPQ scores of these 2 groups of children separately for each mobile app, as shown in Table 9.

Wilcoxon signed rank tests showed that TD children who played the Rage Raver mobile app reported significantly lower reactive aggression after game play, with Z=−2.26 and P=.03. DBD children who used the RegnaTools mobile app reported significantly lower reactive and overall aggression after game play, with Z=−2.21, P=.03 and Z=−2.20, P=.03, respectively.

Figure 4. Perceived playability for mobile apps.

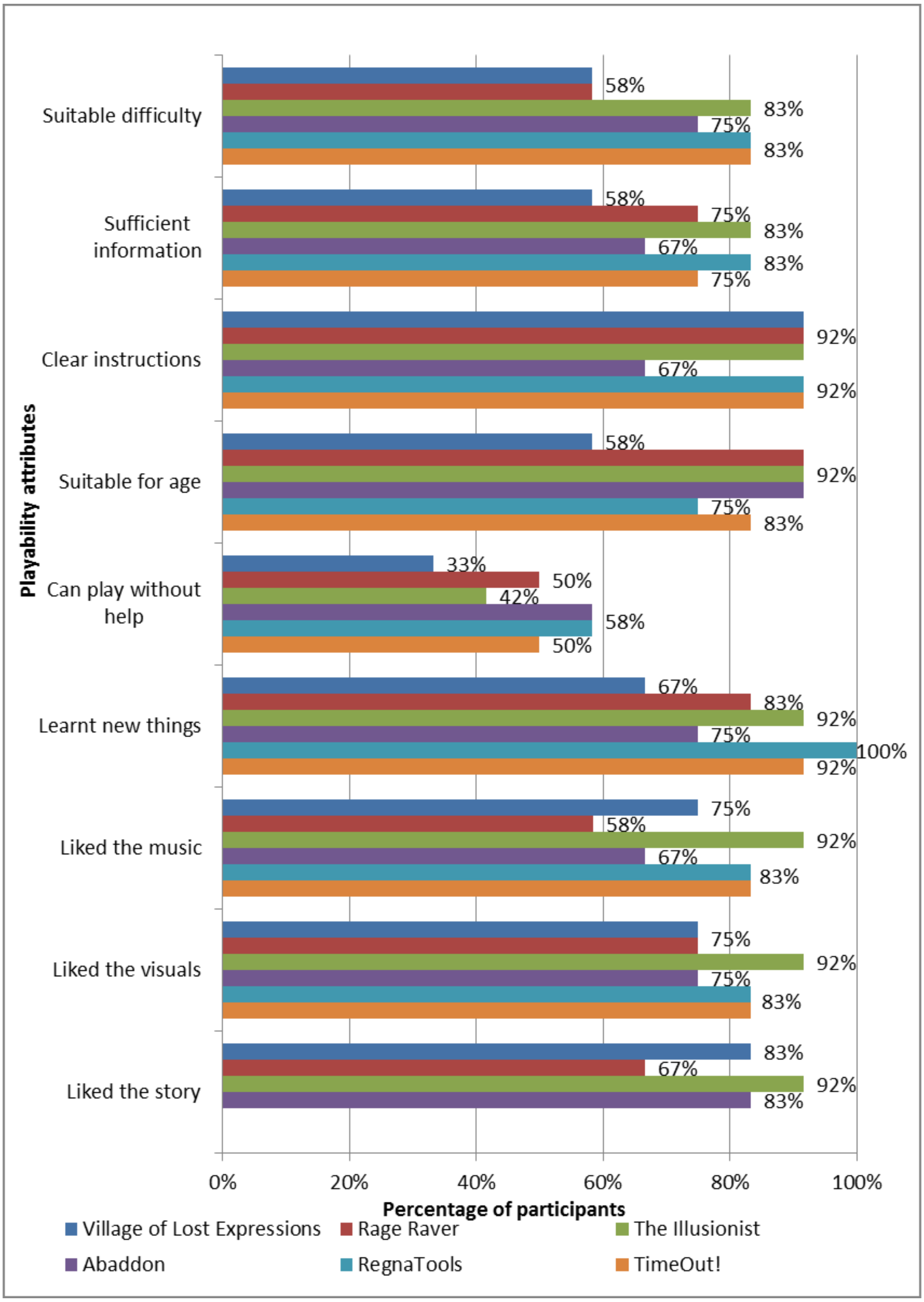

Table 7. Perceived impact scores.

Perceived impact	Typically developing (n=6), mean (SD)	Disruptive behavior disorder (n=6), mean (SD)	Total sample (n=12), mean (SD)
RegnaTools	4.33 (0.48)	4.47 (0.39)	4.40 (0.43)
TimeOut!	4.40 (0.64)	4.50 (0.64)	4.45 (0.62)

Table 8. Descriptive statistics and paired *Z* test analyses for Reactive-Proactive Aggression Questionnaire.

App name and aggression level	Before game, mean (SD)	After game, mean (SD)	*Z* value	*P* value
Village of Lost Expressions (n=12)				
Reactive aggression	0.98 (0.40)	0.83 (0.43)	−2.0	.06
Proactive aggression	0.26 (0.22)	0.23 (0.23)	−0.49	.68
Overall aggression	0.60 (0.27)	0.52 (0.29)	−1.85	.07
Rage Raver (n=12)				
Reactive aggression	0.84 (0.49)	0.40 (0.27)	−2.95	.001
Proactive aggression	0.36 (0.42)	0.51 (0.37)	−1.49	.15
Overall aggression	0.59 (0.42)	0.46 (0.31)	−1.89	.07
The Illusionist (n=12)				
Reactive aggression	0.61 (0.41)	0.52 (0.48)	−1.22	.31
Proactive aggression	0.15 (0.28)	0.17 (0.23)	−0.94	.42
Overall aggression	0.37 (0.29)	0.34 (0.31)	−1.27	.23
Abaddon (n=10)				
Reactive aggression	0.90 (0.37)	0.65 (0.40)	−2.52	.008
Proactive aggression	0.18 (0.23)	0.15 (0.22)	−0.32	.88
Overall aggression	0.52 (0.24)	0.39 (0.26)	−2.52	.008
RegnaTools (n=12)				
Reactive aggression	0.70 (0.42)	0.53 (0.41)	−2.16	.03
Proactive aggression	0.23 (0.27)	0.19 (0.32)	−0.14	.98
Overall aggression	0.45 (0.28)	0.35 (0.29)	−2.14	.03
TimeOut! (n=12)				
Reactive aggression	0.79 (0.26)	0.70 (0.29)	−1.43	.17
Proactive aggression	0.12 (0.16)	0.08 (0.12)	−1.69	.10
Overall aggression	0.44 (0.19)	0.38 (0.18)	−0.85	.53

Table 9. Descriptive statistics and paired *Z* test analyses for Reactive-Proactive Aggression Questionnaire according to condition.

App name and aggression level	Before game, mean (SD)	After game, mean (SD)	*Z* value	*P* value
Village of Lost Expressions (n=12)				
TD[a] (n=6)				
Reactive aggression	1.17 (0.46)	1.00 (0.55)	−1.29	.38
Proactive aggression	0.28 (0.26)	0.19 (0.25)	−1.84	.13
Overall aggression	0.70 (0.32)	0.58 (0.38)	−2.03	.06
DBD[b] (n=6)				
Reactive aggression	0.79 (0.23)	0.67 (0.21)	−1.60	.25
Proactive aggression	0.24 (0.21)	0.26 (0.21)	−0.56	.75
Overall aggression	0.50 (0.18)	0.46 (0.16)	−0.41	.81
Rage Raver (n=12)				
TD[a] (n=6)				
Reactive aggression	0.56 (0.07)	0.29 (0.19)	–2.26	.03
Proactive aggression	0.08 (0.09)	0.35 (0.18)	–2.06	.06
Overall aggression	0.31 (0.05)	0.32 (0.13)	0	.99
DBD[b] (n=6)				
Reactive aggression	1.12 (0.58)	0.52 (0.31)	−2.02	.06
Proactive aggression	0.64 (0.44)	0.68 (0.45)	−0.41	.81
Overall aggression	0.87 (0.44)	0.60 (0.38)	−2.02	.06
The Illusionist (n=12)				
TD[a] (n=7)				
Reactive aggression	0.56 (0.41)	0.51 (0.40)	−1.41	.50
Proactive aggression	0.01 (0.03)	0.05 (0.09)	−0.82	.75
Overall aggression	0.27 (0.21)	0.27 (0.22)	−0.37	.88
DBD[b] (n=5)				
Reactive aggression	0.67 (0.44)	0.53 (0.63)	−1.07	.50
Proactive aggression	0.33 (0.38)	0.35 (0.25)	−0.37	.88
Overall aggression	0.50 (0.37)	0.43 (0.42)	−1.07	.50
Abaddon (n=10)				
TD[a] (n=6)				
Reactive aggression	0.77 (0.35)	0.48 (0.36)	−2.02	.06
Proactive aggression	0.11 (0.15)	0.01 (0.03)	−1.34	.50
Overall aggression	0.43 (0.22)	0.24 (0.16)	−2.02	.06
DBD[b] (n=4)				
Reactive aggression	1.09 (0.34)	0.89 (0.37)	−1.60	.25
Proactive aggression	0.27 (0.32)	0.35 (0.22)	−1.29	.38
Overall aggression	0.66 (0.23)	0.61 (0.23)	−1.60	.25
RegnaTools (n=12)				
TD[a] (n=6)				
Reactive aggression	0.45 (0.34)	0.41 (0.46)	−0.55	.75
Proactive aggression	0.15 (0.26)	0.06 (0.10)	−0.54	.75

App name and aggression level	Before game, mean (SD)	After game, mean (SD)	*Z* value	*P* value
Overall aggression	0.30 (0.21)	0.22 (0.22)	−0.55	.75
DBD[b] (n=6)				
Reactive aggression	0.94 (0.37)	0.65 (0.35)	−2.21	.03
Proactive aggression	0.31 (0.28)	0.32 (0.41)	−0.27	.94
Overall aggression	0.61 (0.27)	0.48 (0.31)	−2.20	.03
TimeOut! (n=12)				
TD[a] (n=6)				
Reactive aggression	0.61 (0.09)	0.56 (0.18)	−0.74	.63
Proactive aggression	0.03 (0.04)	0.03 (0.07)	−0.45	.99
Overall aggression	0.30 (0.04)	0.28 (0.10)	−0.55	.75
DBD[b] (n=6)				
Reactive aggression	0.97 (0.25)	0.85 (0.31)	−1.09	.38
Proactive aggression	0.21 (0.19)	0.14 (0.15)	−1.29	.38
Overall aggression	0.57 (0.19)	0.48 (0.20)	−1.57	.16

[a]TD: typically developing.

[b]DBD: disruptive behavior disorder.

Discussion

This study examined the usability and playability of RegnaTales, a series of 6 interactive mobile apps to address anger and aggression in children. All 6 RegnaTales mobile apps were perceived to be fun, appealing, and were able to sustain the interest of children, similar to what Ooi et al [31] found in their pilot study of first RegnaTales app on a nonclinical sample. Our study further demonstrated that both children with DBD and TD children reported high levels of enjoyment and playability in all 6 mobile apps. These findings are in line with existing literature that supports the use of serious games to deliver therapy or complement therapy in child and adolescent mental health [17,27,39]. However, the children in our study found mobile apps 1 and 3 (Village of Lost Expressions and The Illusionist) more challenging in comparison with other apps and required help in playing these 2 mobile apps. This highlights the need to investigate which aspects of the apps are perceived to be difficult (eg, words within the apps, complexity of instructions, gameplay difficulty, complexity of concepts taught) and indicate that adjustments to these 2 mobile apps are required to improve playability.

Mobile apps 5 and 6 (RegnaTools and TimeOut!) were designed as therapeutic tools to aid the user in the usage and application of anger management skills. Our results showed that most children were keen to continue using RegnaTools and TimeOut! after having used them once (with none of the children indicating *no* to continued usage). This is promising, given that 20% to 25% of users generally stop using a mobile app after the first use [40]. In addition, children who used RegnaTools and TimeOut! generally felt that the apps were helpful for them and rated being more aware of their feelings after using the mobile apps. It was heartening that 96% of them felt that they had learnt skills to manage their anger and 92% of them wanted to learn more skills to manage their anger, indicating a high level of motivation. This could possibly be a result of their positive experience learning these anger management skills in a fun and engaging manner. Crucial to the success of anger management is the application of the anger regulation skills taught in the person’s daily life to target behavioral change [41]. Our findings showed that most of the children were keen to apply the skills learnt from the mobile apps in their daily lives, and they generally felt optimistic that this would be helpful for them. The similarity in high perceived impact scores between children with DBD and TD children showed that RegnaTales was perceived to be helpful not only by children in the clinical population but also among normally developing children. Hence, RegnaTales has the potential to be used as a preventative tool, even before children start developing anger related problems.

Our findings showed that majority (81%) of the children were aware of the explicit goal of RegnaTales (ie, to save the hero’s parents), whereas a smaller percentage (58% to 71%) were aware of the implicit goals of the games (ie, to learn more about themselves and to learn to recognize other’s feelings). This indicates that we were somewhat successful in masking the true intent of the game, which is in line with the objective of a serious game that targets intrinsic motivation through fun [42]. This is important as Shen et al [43] have cautioned that the mere labelling of a game as educational could already elicit negative reactance in a player.

A secondary aim of the study was to ascertain through preliminary analysis, whether RegnaTales could be beneficial in reducing aggression. Although the study was designed as a playability and usability trial, and there was no control group, we observed a significant decrease in reactive and overall aggression measured immediately after game play in children when using some of the mobile apps. Reactive aggression is defensive, retaliatory, and is often a response to real or perceived threats or provocation. On the contrary, proactive aggression is displayed to attain a certain goal, which could be tangible or intangible. Reactive aggression is driven by the feelings of anger, defense, and retaliation, whereas proactive aggression is purposeful, deliberate, and goal-directed and is significantly less associated with anger. Our results indicated that reactive aggression was lower after the usage of Rage Raver, Abaddon, and RegnaTools. These apps were designed to help child users develop an awareness to their feelings, identify the link between emotions and thoughts (especially in the context of anger), as well as learn and practice adaptive anger regulation strategies (eg, deep breathing and cognitive restructuring). Hence the observed reduction in reactive aggression but not proactive aggression offers initial empirical support for the theoretical framework underlying RegnaTales. Furthermore, this finding is consistent with a previous systematic review that highlighted the feasibility of game-based learning in improving outcomes across diverse domains including psychopathology, behavior change, and acquisition of social skills [44]. Another pilot trial showed that children in an inpatient ward had less intense and less frequent anger episodes after a brief course of intervention on a biofeedback game platform based on CBT principles [45]. In our study, reductions in aggression scores were observed after the use of some, but not every, RegnaTales mobile app, despite the fact that many of the mobile apps shared similar content. The various mobile apps also appeared to have differing effects on aggression levels, depending on whether the children had DBD or not. However, these findings are only preliminary, given the small sample size of this study. Future studies with larger samples could shed light on the differential effectiveness of various components of this anger management program, and it would be fruitful to separately investigate their effects on children with DBD and TD children.

Limitations

Some limitations should be taken into account when inferring these findings in relation to existing evidence. First, although our study yielded positive results in terms of the level of enjoyment, playability, and perceived impact of RegnaTales, its effectiveness as an anger management intervention has not been fully evaluated. Furthermore, rigorous evaluation is critical through future studies to fully determine whether RegnaTales would bring about improved outcomes in aggression. In our study, each child played through only 1 of the 6 mobile apps, which meant that each child was only exposed to a part of the anger management program. As RegnaTales was developed to be used as a complete program of 6 mobile apps, where anger management skills are progressively taught and built upon one another with a storyline that flows through, it would be more meaningful if each child were to play through all 6 mobile apps. This could yield differing results in terms of playability and changes in aggression scores. In addition, the findings presented should be regarded as preliminary and interpreted in consideration of the absence of a control group and the use of a pre- and postmethodological design. Another limitation is that our participants in the DBD group were all diagnosed with ADHD and only 1 had an additional diagnosis of ODD and 1 with an additional diagnosis of CD. Our DBD group is unlikely to be representative of the broader DBD spectrum, and it may be worthwhile to replicate the study with groups of children with ODD and CD to see if there are differing results. Future research where RegnaTales is being used and evaluated in the children's natural environment (ie, at home and in school) instead of the clinic setting would be beneficial. Allowing the children to use the mobile apps at their own time and convenience and on their own mobile devices would yield a more accurate picture of the actual usage patterns of the mobile apps. This could also flag practical issues that may affect the usability of the mobile apps (eg, speed and stability of internet connectivity, using the mobile apps on mobile phones with much smaller screens).

Conclusions

Our findings suggest that there is a potential for serious games in mental health interventions for children because of the games' ability to engage and increase intrinsic motivation. RegnaTales is designed to be a serious game that is self-instructional and does not require explicit teaching or guidance. It is less manpower intensive as compared with face-to-face therapy and would be ideal in the context of soaring demand for mental health services for children amidst a mental health service that is growing at a much slower pace. This study provided positive preliminary findings, primarily in the domains of playability and usability of RegnaTales as a serious game. Coupled with future research to further determine its efficacy in reducing anger issues, RegnaTales could be a potential intervention for clinical as well as nonclinical populations.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Screenshots from the RegnaTales mobile apps.

[PDF File (Adobe PDF File), 1MB - games_v7i2e13242_app1.pdf]

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Abbreviations

ADHD: attention-deficit/hyperactivity disorder
CBT: cognitive behavioral therapy

CD: conduct disorder
DBD: disruptive behavior disorders
DSRB: Domain Specific Review Board
eSFQ: extended Short Feedback Questionnaire
ODD: oppositional defiant disorder
PUQ: Playability and Usability Questionnaire
RPQ: Reactive-Proactive Aggression
SPSST: Social Problem-Solving Skills Training
TD: typically developing

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Original Paper

A Motion-Activated Video Game for Prevention of Substance Use Disorder Relapse in Youth: Pilot Randomized Controlled Trial

Lorien C Abroms[1], ScD, MA; Marc Fishman[2], MD; Hoa Vo[2], PhD; Shawn C Chiang[1], MPH; Victoria Somerville[1], MPH; Lawrence Rakhmanov[2], MS; Michael Ruggiero[2], MA; Daniel Greenberg[3], BFA

[1]Department of Prevention and Community Health, Milken Institute School of Public Health, The George Washington University, Washington, DC, United States

[2]Mountain Manor Treatment Center, Baltimore, MD, United States

[3]Media Rez LLC, Washington, DC, United States

Corresponding Author:
Lorien C Abroms, ScD, MA
Department of Prevention and Community Health
Milken Institute School of Public Health
The George Washington University
950 New Hampshire Ave NW Floor 3
Washington, DC, 20037
United States
Phone: 1 2029943518
Email: lorien@gwu.edu

Abstract

Background: Body motion-activated video games are a promising strategy for promoting engagement in and adherence to addiction treatment among youth.

Objective: This pilot randomized trial (N=80) investigated the feasibility of a body motion–activated video game prototype, Recovery Warrior 2.0, targeting relapse prevention in the context of a community inpatient care program for youth.

Methods: Participants aged 15-25 years were recruited from an inpatient drug treatment program and randomized to receive treatment as usual (control) or game play with treatment as usual (intervention). Assessments were conducted at baseline, prior to discharge, and at 4 and 8 weeks postdischarge.

Results: The provision of the game play intervention was found to be feasible in the inpatient setting. On an average, participants in the intervention group played for 36.6 minutes and on 3.6 different days. Participants in the intervention group mostly agreed that they would use the refusal skills taught by the game. Participants in the intervention group reported attending more outpatient counseling sessions than those in the control group (10.8 versus 4.8), but the difference was not significant (*P*=.32). The game had no effect on drug use at 4 or 8 weeks postdischarge, with the exception of a benefit reported at the 4-week follow-up among participants receiving treatment for marijuana addiction (*P*=.04).

Conclusions: Preliminary evidence indicates that a motion-activated video game for addiction recovery appears to be feasible and acceptable for youth within the context of inpatient treatment, but not outpatient treatment. With further development, such games hold promise as a tool for the treatment of youth substance use disorder.

Trial Registration: ClinicalTrials.gov NCT03957798; https://clinicaltrials.gov/show/NCT03957798 (Archived by WebCite at http://www.webcitation.org/78XU6ENB4)

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KEYWORDS

youth; addiction treatment; opioid; marijuana; video game; technology

Introduction

Drug use is recognized as a serious public health problem among adolescents and young adults. In 2015, 37.5% of young adults aged 18-25 years and 17.5% of adolescents aged 12-17 years in the United States reported the use of illicit drugs in that year [1]. Adolescent and young adult substance use disorders (SUDs) are associated with numerous negative outcomes including overdose, HIV transmission, school failure, criminal behavior, and other social problems.

The standard of care for youth with SUDs includes detoxification as needed, followed by traditional psychosocial treatments [2-4]. Psychosocial treatments typically consist of individual and group counseling and may focus on developing skills related to abstinence, such as problem solving, coping, and refusal skills [5]. Although such programs are associated with positive outcomes for youth [5], dropout from treatment remains a major barrier to success [6]. There is a need to develop innovative strategies to improve retention among youth and increase the rates of abstinence.

One promising strategy to promote treatment engagement and adherence is to create models of treatment that offer therapeutic content in game-based formats. Games, including video games, have been explored as therapeutic tools for alleviating a variety of psychological and physical conditions such as stress, anxiety, and mood disorders [7] as well as for treating addiction [8-12]. For addiction, video games have been used to change knowledge and risk perception surrounding drugs and alcohol, develop refusal skills, and help people quit smoking [10-13]. Such games have involved role play [12] and virtual reality exploration [13]. However, it is unclear how experiential games such as motion-activated games using platforms such as the Nintendo Wii and Microsoft Kinect can be used in addiction treatment.

This study builds on an earlier pilot study [14] and examines how a game that runs on an off-the-shelf gaming system (Microsoft Kinect) can be used in SUD treatment by helping patients develop negative associations with drugs and acquire drug-refusal skills [15]. This study is a pilot randomized trial (N=80) of a revised body motion–activated game, Recovery Warrior 2.0, targeting relapse prevention in the context of a community treatment program for SUD among youth. Of interest was the feasibility of the game in the inpatient and outpatient settings, participant ratings of the game, the effect of the game on the mediators of relapse, treatment adherence and retention, and drug use outcomes.

Methods

Study Procedures

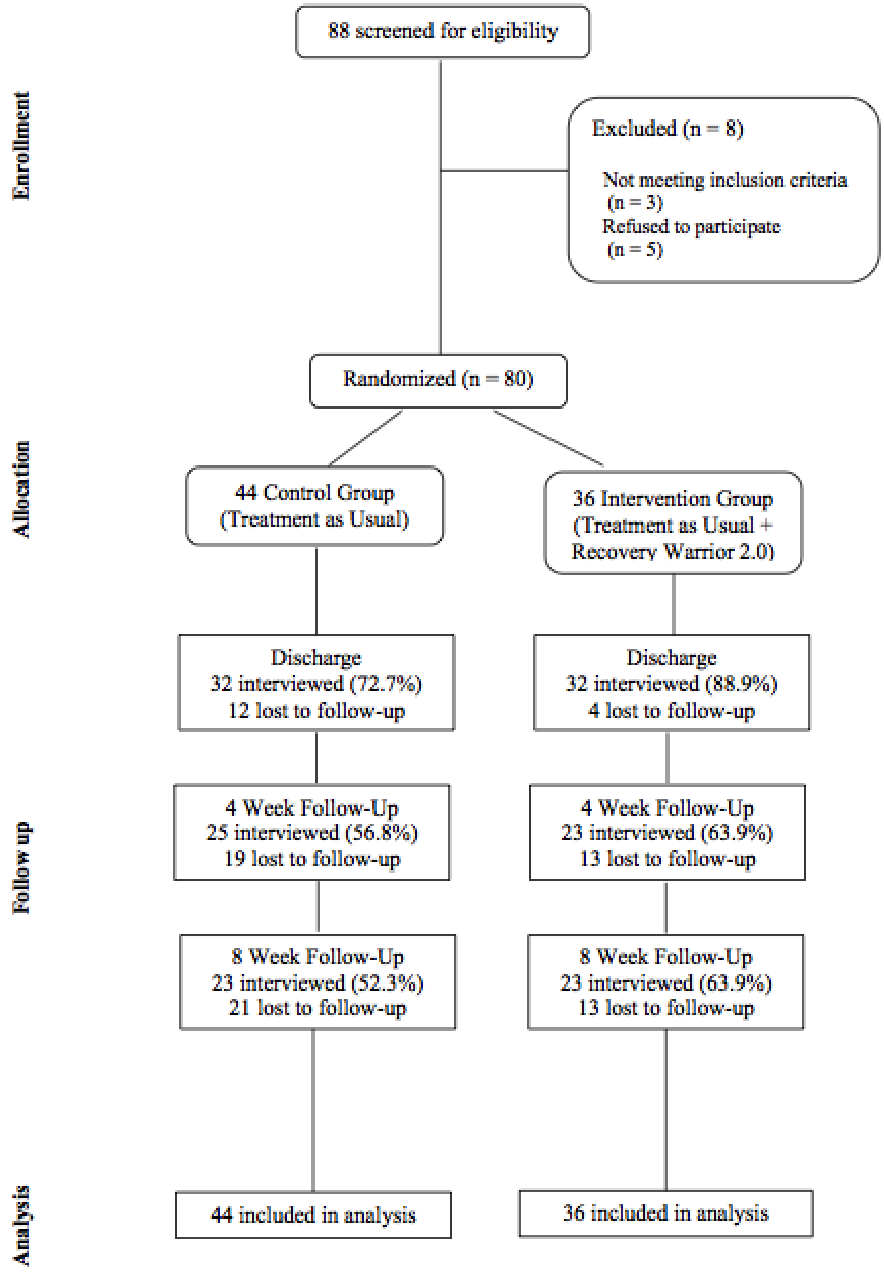
The study was approved by the MaGil Institutional Review Board. Participants were recruited from the short-term inpatient program at the Mountain Manor Treatment Center (MMTC) in Baltimore, MD, between February 5, 2016, and June 21, 2016.

Patients were approached by MMTC research staff about participating in the study within their first few days of inpatient admission, allowing some time for adjustment to the environment and resolution of the most acute phase of withdrawal distress. Interested individuals were assessed for eligibility and, if eligible, provided written consent. For patients under the age of 18 years, assent and parental consent were obtained.

Inclusion criteria were as follows: age of 15-25 years, attending the MMTC inpatient program for primarily opioid or marijuana use disorder treatment, ability to speak English, absence of a comorbid psychiatric condition that would make participation unsafe (eg, acute suicidality or unstable psychosis), and no pregnancy (because of the physical exertion required to play the game).

Once consent was obtained, the participants were given a baseline survey and randomized to receive Recovery Warrior game play with treatment as usual or to receive treatment alone. In addition to the baseline survey, all participants were given an in-person survey prior to inpatient discharge (discharge survey) and another survey by phone at 4 weeks and 8 weeks after discharge from inpatient treatment. Participants were given a US $20 gift card for each survey, plus a bonus gift card of US $10 at 4 weeks and US $20 at 8 weeks. This resulted in a maximum incentive of US $110 for assessments. Phone calls, text messages, Facebook messages, and subject interception at MMTC outpatient treatment were used to remind participants of their upcoming follow-up surveys. For the 4- and 8-week surveys, up to 15 contact attempts were made per survey before considering the case as a missed follow-up. Participant flow can be seen in Figure 1.

Figure 1. CONSORT flow diagram. Participant enrollment and follow-up.



Recovery Warrior Game Play With Treatment as Usual

In addition to their usual care, participants randomized to game play were given the opportunity to participate in a game play session 3 times/week for the length of their stay in the residential (inpatient) program. Typical inpatient stays at MMTC are for 9 days, and thus, it was expected that participants would have 4 game play sessions over the course of their inpatient stay. Participants in the intervention group who transitioned to outpatient care at MMTC were given an additional weekly opportunity to play the game for 4 weeks. The goal was for each game play session to last 1 hour and include 3-5 participants, with each participant playing for at least 10 minutes and no more than 15 minutes per session. Players would take turns, with each player playing one at a time and the others watching and encouraging him/her. Each 1-hour session included an introduction to the game by the counselor (2 min), game play, and an informal debriefing by the counselor about lessons learned in the game (8-10 mins). In the first session, the participants were directed to play each game, so that they would have an experience of each of the games. Subsequently, participants could choose to play any of the games. Sessions were offered in a dedicated room at the MMTC.

Recovery Warrior 2.0 [16] was developed for use with Microsoft Kinect running on a Windows personal computer. The 2.0 version was improved from an initial version that was previously pilot tested [17] and consisted of a suite of several games. All games made use of whole-body motion detection and the same voice-recognition feature. Body motions included a variety of arm, leg, and whole-body movements to physically enact the motions of destroying or evading images of drugs and drug paraphernalia. Voice features consisted of recognition of the refusal phrase “I’m Clean” Players could say or shout “I’m Clean” in order to gain additional strength for their game play avatar. All game art was created in a hyperrealistic, idealized, heroic style, which is the preferred style choice as per a focus group in an earlier work [17]. Across games, players were given a choice of several distinct hyperrealistic avatars. The counselor set up the game, so that the drug images would correspond to the drug being treated for (eg, opioid patients would see syringes, spoons, pill bottles, and pills as part of game play, while marijuana patients were exposed to marijuana cigarettes, baggies of marijuana, and bongs). Players could choose whether to play in a mode where they destroyed drugs, avoided drugs, or discerned prosocial “goodies” from drugs while avoiding drugs and collecting “goodies.” Goodies included images of items such as graduation caps, car keys, and footballs.

The following games were tested: Recovery Ninja (destroy drugs), Recovery Ninja+Goodies (destroy and discern), Recovery Climber (avoid drugs), Recovery Racer (destroy drugs), Recovery Racer+Goodies (destroy and discern), Recovery Runner (avoid drugs), and Recovery Runner+Goodies (avoid and discern). For example, the goal of Recovery Ninja is to destroy drugs that fly at the player’s avatar. The player must make chopping, punching, and hitting gestures to destroy the drugs that fly across the screen in order to win the game while periodically shouting “I’m Clean” to power up. Another example is Recovery Runner. In this game, the player runs through a dark city, which progressively brightens as the player succeeds in staying away from drugs. Instead of destroying drugs (as in Recovery Ninja), the player must avoid them by physically ducking, dodging, and jumping to control the avatar’s movements and avoid touching the drugs. As with other games, the player periodically shouts “I’m Clean” to gain additional power. See Multimedia Appendix 1 for more details and screenshots of the games.

Theoretical Mechanism of Recovery Warrior

The development of the game was based on the social cognitive theory, repetition priming, and the reinforcement theory of motivation [17,18]. Developed first in 1960, the social cognitive theory considers ways in which individuals acquire and maintain new behaviors while considering the social environment in which the individuals perform the behavior. Based on social cognitive theory, it is hypothesized that by repeatedly role playing destroying drugs/avoiding drugs in the context of the game, players will experience increases in their self-efficacy and behavioral capability for drug refusal and avoidance in the real world [18]. This may occur because players develop self-schemas of themselves as drug destroyers or avoiders rather than users [19]. Furthermore, drug refusal skills and self-schemas as nonusers will be further enhanced by the constant repetition of the phrase “I’m Clean” throughout the game, so that participants will be primed to use it if offered drugs in a future situation [20].

Additionally, based on the reinforcement theory of motivation, we hypothesize that youth will be better able to learn these skills if the learning process is paired with rewards. In this case, rewards associated with playing immersive video games may include positive feelings as a sense of mastery; eustress; and pleasure, activation, and arousal from the game-based exercise and physical exertion [21,22]. Finally, because this game is being designed as a social game to be played in the company of others in treatment, it is also hypothesized that social learning will contribute to the mastery of refusal skills and drug avoidance [18]. Participants will learn the skills of avoiding drugs/refusing drugs by not only repeatedly playing themselves, but also watching others practice these skills in the context of the game.

Treatment as Usual

Treatment as usual at the MMTC consisted of individual and group counseling as well as pharmacotherapy, where recommended. MMTC is a Joint Commission-accredited community treatment program for SUDs and co-occurring mental health conditions. Typically, patients stay in the inpatient program for 1-2 weeks and then transition to the outpatient program at the MMTC or another treatment center.

Measures

The baseline survey included measures of the demographic characteristics of participants, video game use, and history of drug use of participants. Participants were asked about the primary drug that they were in treatment for. Opioid and marijuana use at follow-up was ascertained by self-report of any use in the past 7 and 30 days, using the Time Line Follow Back tool, as well as the date of last use.

For the intervention group at the 4-week follow-up, participants were asked about their perceptions of the most helpful game among the games played and the mode of game play that was seen as most helpful (eg, destroy drugs, avoid drugs, and collect goodies). Computer records of game play were also used to measure minutes of game play for each participant and days of game play. Measures of user engagement in Recovery Warrior were collected through a retrospective review of the computer records from game play. The system recorded each time a user played the game in minutes of game play. For each participant, the number of total minutes of game play was calculated across the intervention period.

Additionally, the 4-week follow-up survey assessed refusal skills taught by the game. Refusal skills were measured by asking participants if they agreed that they would use the phrase “I’m Clean” to refuse drugs (1=not agree to 5=highly agree), if they had used the phrase “I’m Clean” since discharge to refuse drugs, and if the phrase “I’m Clean” still rings in their head (not at all, less than once per week, a few times a week, or more often).

For both groups, psychosocial mediators of recovery, self-efficacy, and cravings were measured. Self-efficacy for refusal of drugs was measured using the Marijuana Resistance Self-Efficacy scale at baseline, discharge, and follow-up surveys [23,24]. It used a 4-item, 4-point scale (1=very easy to 4=very hard) that asked participants how easy or hard it would be to refuse the drug if offered and explain why they did not want it, why they wanted to avoid the situation in the first place, and why they wanted to leave the situation. It was adapted so that there was a similar version for opioid use. Participants were only asked about the primary drug for which they enrolled in treatment (ie, marijuana or opioids).

For cravings, the 5-item Penn Alcohol Craving Scale [25] was included at baseline, discharge, and postdischarge follow-up surveys, but modified to apply to marijuana and opioid use. It assessed the intensity of a participant's cravings (0=none at all to 6=very strong; sum of a maximum total of 30 points).

Treatment rating was measured in three ways. First, it was measured with the Counselor Alliance Scale, which was taken from the Working Alliance Inventory [26-28], and used to measure treatment progress with the counselor at discharge, 4 weeks, and 8 weeks. The Counselor Alliance Scale uses 7-items and 7-points to measure how well participants believe counselors are working with them to improve their situation (1=never to 7=always). The treatment rating was also measured by asking participants about their satisfaction with inpatient care at the time of discharge and satisfaction with outpatient care at the 4-week and 8-week follow-up surveys.

Treatment use was measured by self-report of the use of outpatient services including meeting a doctor, meeting a counselor, attending group sessions, taking medications, and other services. The total number of services used was summed up for each participant. Participants were also asked at the 4-week and 8-week follow-ups about the number of outpatient counseling sessions attended in the past 30 days. Drug use outcomes were measured by asking participants at the 4-week and 8-week surveys if they had used the drug for which they received treatment (eg, opiates or marijuana), over the past 7 and 30 days.

Analysis

Means and SDs or percentages were calculated for key variables and compared between intervention and control groups. Chi-squared tests were used for categorical variables, and two-tailed *t* tests were used for continuous variables. Outcome analyses were conducted both with collected data alone and with missing values imputed as positive for drug use. In addition to the combined analyses, outcome analyses were conducted separately for marijuana and opioid patients.

Results

Participant Characteristics

Eighty participants were recruited, of which 36 were randomized to the intervention group and 44 were randomized to the control group. Of the 80 participants, 64 completed the discharge interview (80.0%), 48 completed the 4-week follow-up interview (60.0%), and 46 completed the 8-week follow-up interview (57.5%). There were no significant differences between groups in terms of survey completion.

Most participants were between the ages of 18 and 20 years. More than half of the participants were not attending school at the time of the study (65.0%), while 26.3% were in high school and the other 8.8% were in college. The majority of participants were male (77.5%). Most participants identified themselves as white (63.8%) or black (28.8%). Half of the participants had a mother who finished high school/General Education Development as the highest level of education (50.0%) and almost half had a father with a similar level of education (46.3%). Participants were in treatment for opioid (57.5%) or marijuana (42.5%) use disorder. Almost half of the participants reported daily prestudy video game use (46.3%) and, to a lesser extent, weekly use (18.8%), monthly use (23.8%), and none at all (11.3%). Most participants in our sample spent 4-6 days at the MMTC (51.3%), and fewer spent 7-10 days (31.3%) (Table 1).

Table 1. Demographic characteristics and drug use history of participants.

Characteristics	All participants (N=80)	Intervention group (N=36)	Control group (N=44)
Age (years), mean (SD)			
<18	15 (18.8)	9 (25.0)	6 (13.6)
18-20	44 (55.0)	21 (58.3)	23 (52.3)
21-25	21 (26.3)	6 (16.7)	15 (34.1)
Grade, n (%)			
8th-12th	21 (26.3)	13 (36.1)	8 (18.2)
College	7 (8.8)	1 (2.8)	6 (13.6)
Not in school	52 (65.0)	22 (61.1)	30 (68.2)
Gender, n (%)			
Male	62 (77.5)	32 (88.9)	30 (68.2)[a]
Female	18 (22.5)	4 (11.1)	14 (31.8)
Race/ethnicity, n (%)			
Black	23 (28.8)	9 (25.0)	14 (31.8)
White	51 (63.8)	23 (63.9)	28 (63.6)
Other[b]	6 (7.5)	4 (11.1)	2 (4.5)
Mother’s education, n (%)			
Did not graduate high school	9 (11.3)	3 (8.3)	6 (13.6)
High school graduate/GED[c]	40 (50.0)	20 (55.6)	20 (45.5)
College or higher	27 (33.8)	10 (27.8)	17 (38.6)
No response	4 (5.0)	3 (8.3)	1 (2.3)
Father’s education, n (%)			
Did not graduate high school	14 (17.5)	7 (19.4)	7 (15.9)
High school graduate/GED	37 (46.3)	13 (36.1)	24 (54.5)
College or higher	12 (15.0)	7 (19.4)	5 (11.4)
No response	17 (21.3)	9 (25.0)	8 (18.2)
Primary drug of treatment, n (%)			
Marijuana	34 (42.5)	18 (50.0)	16 (36.4)
Opiates	46 (57.5)	18 (50.0)	28 (63.6)
Ever used intravenous drugs, n (%)			
Used	37 (46.3)	16 (44.4)	21 (47.7)
Did not use	43 (53.8)	20 (55.6)	23 (52.3)
Used any drug in the past 7 days, n (%)			
Yes	41 (51.3)	18 (50.0)	23 (52.3)
No	39 (48.8)	18 (50.0)	21 (47.7)
Date last drug used , n (%)			
<1 month	72 (90.0)	31 (86.1)	41 (93.2)
1-2 months	8 (10.0)	5 (13.9)	3 (6.8)
>2 months	0 (0.0)	0 (0.0)	0 (0.0)
Current video game use, n (%)			
Most days/daily	37 (46.3)	14 (38.9)	23 (52.3)
1-2 times/week	15 (18.8)	5 (13.9)	10 (22.7)

Characteristics	All participants (N=80)	Intervention group (N=36)	Control group (N=44)
Few times a month	19 (23.8)	12 (33.3)	7 (15.9)
Not at all	9 (11.3)	5 (13.9)	4 (9.1)
Total days at the Mountain Manor Treatment Center, n (%)			
1-3 days	10 (12.5)	4 (11.1)	6 (13.6)
4-6 days	41 (51.3)	17 (47.2)	24 (54.5)
7-10 days	25 (31.3)	12 (33.3)	13 (29.5)
≥10 days	4 (5.0)	3 (8.3)	1 (2.3)
Baseline craving, mean (SD)	7.8 (3.5)	8.1 (3.2)	7.7 (3.8)
Baseline self-efficacy, mean (SD)	9.2 (3.6)	8.7 (3.5)	9.7 (3.8)

[a]*P*=.03.

[b]The category "other" includes Asian, Hispanic, or Latino and those who self-identified as "other."

[c]GED: General Education Development.

Overall, there were no significant differences in the demographic items between the intervention and control groups, with the exception of gender: The intervention group was more likely to have male patients than female patients (*P*=.03) Participants who completed the 4-week survey were similar to noncompleters in all demographic variables. As expected, there were some differences in the demographic characteristics of marijuana and opioid users; the opioid users were more likely to be older (*P*<.001) and not in school (*P*<.001).

Game Rating and Engagement

Intervention participants (n=36) played for an average of 36.6 minutes during the total intervention, of which 35.7 minutes (average) was during inpatient and 0.9 minutes was during outpatient treatment. Participants played for 3.6 days, of which an average of 3.4 days was during inpatient treatment and 0.2 days was during outpatient treatment. Only 3 intervention participants (8.3%) played the game during the outpatient period. For these participants, the average number of outpatient game play days was 2 days, and the average number of game play minutes was 0.9 minutes (Table 2).

Among the intervention group participants who completed the discharge survey (n=32, 88.9%), participants expressed views on their game play preferences: Recovery Ninja was most frequently rated as the most helpful game, followed by Recovery Runner+Goodies. Participants noted that the most helpful mode of game play was avoiding drugs while collecting goodies (eg, Recovery Runner+Goodies), followed by destroying drugs (eg, Recovery Ninja).

The games used the phrase "I'm Clean" to train participants on drug-refusal skills. At 4 weeks of follow-up, among intervention participants who completed the survey (n=23, 63.9%), the majority of participants agreed or strongly agreed that they could imagine using the phase "I'm Clean" in their real lives to refuse drug offers, and the majority stated that when they were not playing the game, the phrase "I'm Clean" rang in their head either a few times a week or daily. Finally, the slight majority (52.2%) stated that they had used the phrase "I'm Clean" to refuse drugs since leaving inpatient treatment.

Table 2. Game rating and engagement in the intervention group.

Measure	Value
Game rating[a]	
Most helpful game, n (%)	
Ninja	8 (26.7)
Ninja+Goodies	3 (10.0)
Climber	3 (10.0)
Racer	0 (0.0)
Racer+Goodies	0 (0.0)
Runner	3 (10.0)
Runner+Goodies	7 (23.3)
I have no preferences, all equally enjoyable	6 (20.0)
Mode of game play most helpful, n (%)	
Destroy drugs (Ninja, Racer)	12 (40.0)
Avoid drugs (Runner, Climber)	4 (13.3)
Avoid drugs and collect goodies (Ninja/Racer/Runner+Goodies)	14 (46.7)
Game engagement[b]	
Total game play, minutes	36.6
Inpatient minutes	35.7
Outpatient minutes	0.9
Total game play, days	3.6
Inpatient days	3.4
Outpatient days	0.2
Game refusal skills[c] , n (%)	
Would use "I'm Clean" to refuse drugs (scale: 1-5 points)	3.5 (1.5)
Used "I'm Clean" to refuse drugs	
Yes	12 (52.2)
No	11 (47.8)
Phrase "I'm Clean" rings in my head	
A few times a week or more	13 (56.5)
Less than once per week	4 (17.4)
Not at all	6 (26.1)

[a]Measured at discharge (n=32).

[b]Game engagement items are based on computer records of use (n=36).

[c]Measured at 4 weeks postdischarge (n=23).

Self-Efficacy, Craving, Treatment Rating, and Treatment Use

Overall, cravings declined for both groups from baseline to the 4-week follow up and to the 8-week follow-up, but the differences between groups were not statistically significant (*P*=.45). Self-efficacy fluctuated slightly between baseline, the 4-week follow-up, and the 8-week follow-up but did not change widely between the intervention and control groups (Table 3). These findings do not support the hypothesis that participants who received Recovery Warrior 2.0 reported greater improvements in the predicted mediators of addiction recovery compared to those in usual care.

Measures of treatment rating and treatment use did not reveal differences between groups. Both groups had similar scores on the Counselor Alliance Scale and on their satisfaction with inpatient and outpatient care. Additionally, the utilization of outpatient services did not differ by group at 4 weeks. By 8 weeks, participants in the intervention group reported having attended more outpatient counseling sessions (10.08 vs 4.80), but the difference did not reach significance (*P*=.19; Table 3).

Table 3. Effect of game on psychosocial measures of recovery, treatment rating, and treatment use. All values are presented as mean (SD).

Measure	Discharge		At 4-week follow-up		At 8-week follow-up	
	Intervention (n=32)	Control (n=32)	Intervention (n=23)	Control (n=25)	Intervention (n=23)	Control (n=23)
Self-efficacy[a]	6.8 (2.5)	7.6 (3.5)	6.8 (2.4)	8.2 (3.5)	6.8 (1.9)	6.3 (2.5)
Drug craving[a]	5.4 (2.8)	6.9 (3.5)	4.3 (2.2)	5.1 (3.8)	4.9 (2.6)	5.9 (3.7)
Counselor Alliance Scale[a]	32.3 (11.4)	35.5 (10.3)	35.0 (10.6)	35.8 (7.5)	31.5 (10.3)	36.4 (8.9)
Satisfaction with inpatient care[a]	2.4 (1.2)	2.4 (1.1)	N/A[b]	N/A	N/A	N/A
Satisfaction with outpatient care[a]	N/A	N/A	1.8 (0.8)	2.0 (0.7)	2.1 (1.0)	2.1 (0.9)
Total number of outpatient services used	N/A	N/A	2.7 (1.1)	2.7 (1.0)	2.2 (1.6)	1.7 (1.5)
Number of outpatient counseling sessions attended (in past 30 days)	N/A	N/A	10.2 (5.6)	8.4 (6.6)	10.1 (18.7)	4.8 (5.5)

[a]The values presented are scores.

[b]N/A: not applicable.

Effect of Game on Drug Use

At the 4- and 8-week follow-up periods, there were no significant differences in the rates of either past 7-day and past 30-day abstinences between groups, considering both imputed and complete cases and marijuana and opioid patients together. Analyses were also repeated while controlling for gender, which was not balanced between groups at baseline. Results were similar for gender-adjusted and unadjusted models. The unadjusted models are presented in Table 4.

Although the differences were not significant in the combined marijuana and opioid analysis, the patients were analyzed separately. For analyses with drug use values imputed for the missing values, at 4 weeks after the intervention, 13 of the marijuana patients in the intervention group (72.22%) reported that they did not use drugs in the past 7 days compared with 6 people in the control group (37.50%; *P*=.04). Other results for marijuana patients (past 30 days at 4 weeks and past 7 and 30 days at 8 weeks) were not found to be significant (*P*=.81). No differences were observed for opioid patients.

Table 4. Effect of the game on drug use.

Follow-up survey/measure	Drug use values imputed			Complete cases		
	Intervention (N=36), n (%)	Control (N=44), n (%)	Unadjusted risk ratio (95% CI)	Intervention (N=24), n (%)	Control (N=27), n (%)	Unadjusted risk ratio (95% CI)
At 4-week follow-up						
Not used in the past 7 days	22 (61.1)	19 (43.2)	1.4 (0.9-2.2)	22 (91.7)	19 (70.4)	1.3 (1.0-1.7)
Not used in the past 30 days	18 (50.0)	17 (38.6)	1.3 (0.8-2.1)	18 (75.0)	17 (63.0)	1.2 (0.8-1.7)
At 8-week follow-up						
Not used in the past 7 days	16 (44.4)	19 (43.2)	1.0 (0.6-1.7)	16 (66.7)	19 (76.0)	0.9 (0.6-1.3)
Not used in the past 30 days	15 (41.7)	16 (36.4)	1.2 (0.7-2.0)	15 (62.5)	16 (64.0)	1.0 (0.6-1.5)

Discussion

Principal Findings

This study represents the first randomized trial of a body motion–activated game targeting drug-relapse prevention for patients who were enrolled in an inpatient treatment program and the first trial of a motion-activated video game aimed at the treatment of addiction in youth in any setting. The program was found to be feasible, primarily in the inpatient setting. Participants in the intervention group played for 3.6 days on an average, which was close to the 4 days of game play target set by the study protocol for inpatient care. Those randomized to the game play group mostly agreed that they would use the refusal skills taught by the game, and a near majority reported that they used those skills 4 weeks after discharge. There was a trend for those in the intervention group to report attending more outpatient counseling sessions than the control group, but the differences were not significant. There was a trend for an effect of the game on past 7- and 30-day drug use at 4 weeks postdischarge, with a significant benefit for a subgroup of participants who were in treatment for marijuana use disorder. No evidence was found that the game worked by differentially improving self-efficacy for drug refusal or reducing cravings.

Overall, the dose of game play was small, limiting the potential for demonstration of effect. Contrary to the intended protocol, most intervention participants never received any game play after discharge from inpatient treatment. Thus, as designed, this study could not address the question of the effects of continued exposure to game play in the outpatient setting. Difficulties encountered for outpatient treatment were largely due to characteristics of the trial. Only about half of the intervention participants came to the MMTC for outpatient care. For the few who did come, game play could only be offered in the outpatient setting on an individual basis, as there were too few trial participants at any given time to form a group. Participants expressed that they did not want to leave their outpatient group counseling sessions for individual game play and therefore declined to play in this setting. Future tests of the game may benefit from careful consideration of group dynamics, and where possible, deliver the game in a group, social format rather than in an individual game format. Furthermore, if patients are unlikely to get access to the game in their outpatient treatment setting, additional opportunities should be developed for game play in other settings, perhaps using home-based play on a computer or smartphone. This may have the potential to make the effects of the game last longer and should be investigated further.

We found some effect of the game for marijuana participants but not opioid participants; this may indicate that the game is more promising for the former subgroup. It is possible that these patients are younger, with lower addiction severity and chronicity, and more likely to respond to a behavioral intervention. A game may also be more consistent with younger patients' preferences for less "serious" and more experiential treatments. It may be that higher doses of game play are needed for more entrenched physiological addiction such as that for opiates.

Although originally hypothesized as mediators of the effect of the game, the game play did not appear to increase the levels of self-efficacy for drug refusal, as self-efficacy remained constant. It is possible that the game does not operate as hypothesized through drug refusal self-efficacy. It also appears that the game does not differentially decrease cravings. Other mechanisms such as repetition priming can be explored as mechanisms in future studies of the game.

Strengths

Strengths of this study include that it was the first randomized study of a motion-activated video game aimed at the treatment of addiction in youth. The game was built around an affordable off-the-shelf motion-sensing peripheral—Microsoft Kinect—widely used by youth, which is most famous for its use with Microsoft's popular Xbox video game platform. The potential for dissemination is high, with the possibility for play not only in treatment centers, but also at home.

Limitations

The study experienced significant loss to follow-up, as about 40% of participants were not available for the 4-week and the 8-week follow-up interviews. Although this is a high level of attrition, this level is not unusual for youth attending drug-treatment facilities, as participants following discharge are at high risk for dropout, relapse, incarceration, or readmission to inpatient treatment. Additionally, marijuana and opioid patients were found to have different demographic characteristics and possibly different responses to the game. In addition, treatment adherence in the intervention group was low in the postdischarge period, and few participants experienced game play after leaving the inpatient setting. It should also be noted that while current video game use was captured in this study, the use of Microsoft Kinect specifically was not captured and may have implications for the dose and fidelity of the intervention. Another limitation is that the intervention group was not balanced with the control group for gender, as there were fewer female patients in the intervention group than in the control group, although we did not find different effects of the game by gender. Finally, the drug use outcome measures in this study relied on self-report only and because of social desirability, they may represent undercounts of relapse rates. Future studies should use drug testing to verify abstinence.

Conclusions

This pilot study provides encouraging proof-of-concept results to show that an early prototype of the Recovery Warrior game is feasible and acceptable in inpatient treatment settings and produces some encouraging outcomes. Future larger studies with a more refined version of the game are warranted to test its implementation in outpatient treatment settings, its overall efficacy, and how to best adapt it to different drug-using subgroups.

Acknowledgments

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Conflicts of Interest

DG is the President of Media Rez LLC. Media Rez is planning to sell Recovery Warrior as a commercial venture. LA has the potential to benefit financially from the sale of Recovery Warrior. MF is the Medical Director of Mountain Manor Treatment Center (MMTC), where patients were enrolled in this study. MF is also a part-time faculty member of the Johns Hopkins University and a beneficiary of the trust that owns MMTC. In addition, MF serves on the governing board of the trust and the Board of Directors of MMTC. This arrangement has been reviewed and approved by the Johns Hopkins University in accordance with its conflict of interest policies. SC, LR, MR, VS, and HV declare no conflicts of interest.

Multimedia Appendix 1

Details and screenshots of the games.

[PDF File (Adobe PDF File), 415KB - games_v7i2e11716_app1.pdf]

Multimedia Appendix 2

CONSORT-EHEALTH checklist (V 1.6.1).

[PDF File (Adobe PDF File), 14MB - games_v7i2e11716_app2.pdf]

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Abbreviations

GED: General Education Development
MMTC: Mountain Manor Treatment Center
SUD: substance use disorder

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Original Paper

A Web-Based Serious Game for Health to Reduce Perioperative Anxiety and Pain in Children (CliniPup): Pilot Randomized Controlled Trial

Connor Buffel[1], BSc, MBT; June van Aalst[2], BSc, MSc; Anne-Marie Bangels[3], BSc; Jaan Toelen[3], MD, PhD; Karel Allegaert[3,4], MD, PhD; Sarah Verschueren[5], PhD; Geert Vander Stichele[5], MSc, PharmD

[1]MindLab Interactive AI Inc, Edmonton, AB, Canada

[2]Division of Nuclear Medicine and Molecular Imaging, Department of Imaging and Pathology, KU Leuven, Leuven, Belgium

[3]Department of Development and Regeneration, KU Leuven, Leuven, Belgium

[4]Division of Neonatology, Department of Pediatrics, Erasmus Medical Center–Sophia Children's Hospital, Rotterdam, Netherlands

[5]MindBytes BVBA, Merksplas, Belgium

Corresponding Author:
Sarah Verschueren, PhD
MindBytes BVBA
Schoondreef 7
Merksplas,
Belgium
Phone: 32 476 75 35 16
Email: sarahverschueren@hotmail.com

Abstract

Background: As pediatric ambulatory surgeries are rising and existing methods to reduce perioperative anxiety and pain are lacking in this population, a serious game for health (SGH), CliniPup, was developed to address this unmet need. CliniPup was generated using the SERES framework for serious game development.

Objective: The goal of the research was to clinically evaluate CliniPup as an adjunct therapy to existing pharmacological interventions aimed at reducing perioperative anxiety and pain in children undergoing ambulatory surgery.

Methods: CliniPup was evaluated in a prospective randomized controlled pilot trial in 20 children aged 6 to 10 years who underwent elective surgery and their parents. Study participants were randomly assigned to the test (n=12) or control group (n=8). Children in the test group played CliniPup 2 days prior to surgery, and children in the control group received standard of care. On the day of surgery, pediatric anxiety was measured with the modified Yale Preoperative Anxiety Scale and parental anxiety was assessed with the State-Trait Anxiety Inventory. Pediatric postoperative pain was assessed by the Wong-Baker Faces Pain Rating Scale. Child and parent user experience and satisfaction were also evaluated in the test group using structured questionnaires.

Results: Despite the small sample, preoperative anxiety scores were significantly lower (*P*=.01) in children who played CliniPup prior to surgery compared to controls. Parental preoperative anxiety scores were also lower in the test group (*P*=.10) but did not reach significance. No significant differences were observed in postoperative pain scores between groups (*P*=.54). The evaluation of user experience and satisfaction revealed that both children and parents were satisfied with CliniPup and would recommend the game to peers.

Conclusions: Results of the pilot trial introduce CliniPup as a potentially effective and attractive adjunct therapy to reduce preoperative anxiety in children undergoing ambulatory surgery with a trend toward positive impact on parental preoperative anxiety. These results support the use of the SERES framework to generate an evidence-based SGH that results in positive health outcomes for patients. Based on these preliminary findings, we propose a research agenda to further develop and investigate this tool.

Trial Registration: ClinicalTrials.gov NCT03874442; https://clinicaltrials.gov/ct2/show/NCT03874442 (Archived by WebCite at http://www.webcitation.org/78KZab8qc)

(JMIR Serious Games 2019;7(2):e12431) doi:10.2196/12431

KEYWORDS

serious games for health; behavior change; perioperative pain; perioperative anxiety; pediatric; ambulatory surgery

Introduction

Background

Ambulatory surgeries are increasing at a significant rate, and procedures are associated with high levels of perioperative pain and anxiety [1-4]. This is particularly true in children, with 40% to 60% experiencing high levels of anxiety on the day of surgery, and more than 30% experiencing moderate to severe postoperative pain [1,2,4,5]. This leads to both acute and long-term physical and psychosocial outcomes [5-7].

The current management of perioperative anxiety and pain is particularly difficult in children and is considered inadequate due to the limitations of existing interventions [6,8,9]. Specifically, the use of alternative nonpharmacological interventions to reduce anxiety is limited by cost, time restrictions, availability, and efficacy [6,7,9,10]. In addition, pharmacological interventions are limited by adverse effects, inconsistent prescribing practices, and poor parental assessment and understanding of pain [11-18]. Therefore there is a need to develop additional interventions to better address perioperative anxiety and pain.

Digital interventions have the potential to prepare, educate, and/or distract children, which may result in health outcome benefits such as reductions in perioperative anxiety [7,19-22]. MindBytes is focused on empowering and educating individuals using interactive digital tools and developed a serious game for health (SGH), CliniPup, to prepare children and their parents for surgery [23].

CliniPup has the potential to address limitations of existing nonpharmacological interventions as it is relatively low cost, requires minimal time and resources, and could be widely deployed. Moreover, it has the potential for synergy as an adjunct to pharmacological interventions by preparing parents for postoperative pain management. In addition, it has the potential to address gaps of distraction techniques by preparing both children and parents in a fun and intuitive manner [23]. Although it is clear that preparing both children and parents is vital, this research focused mainly on children due to the challenge of addressing child and parental learning objectives in a single SGH [6,7,13,24].

This study evaluated CliniPup's usability, safety, and effectiveness in a pilot trial with the target population.

Objective

The objective of this research was to evaluate CliniPup's usability and clinical impact in comparison to the standard of care in a pilot trial.

Methods

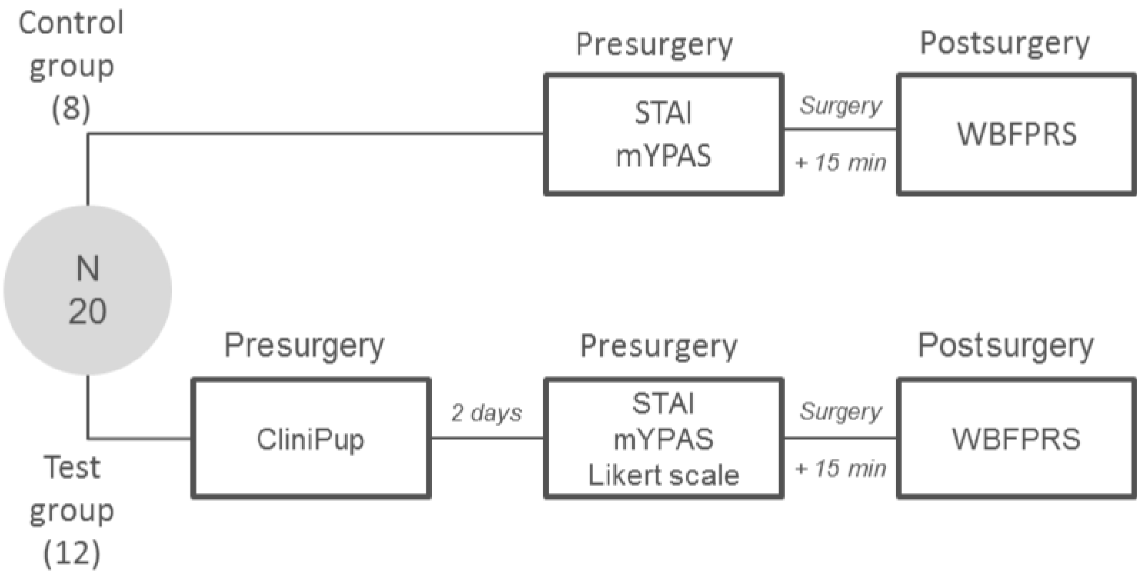
Pilot Trial

CliniPup's impact on perioperative pain and anxiety in children was evaluated in a pilot clinical trial with 20 children aged 6 to 10 years who were with their parents and undergoing ambulatory surgery. Several secondary outcomes were also evaluated in the trial such as parental anxiety and SGH usability.

Trial Design

The study was a prospective, randomized, 2-armed controlled pilot study conducted at 2 institutions in Belgium (RZ Tienen, Campus Mariendal and RZ Tienen, Medisch Centrum Aarschot) from April to May 2016. Study participants were assigned to a test group (n=12) or a control group (n=8) using a block randomization technique dependent on the week of contact by the researcher (eg, one week participants were randomized to test group and the following week, participants were randomized to the control group). Children in the test group played CliniPup 2 days prior to surgery. On the day of surgery, children's anxiety was measured with the modified Yale Preoperative Anxiety Scale (mYPAS) and parental anxiety was assessed with the State-Trait Anxiety Inventory (STAI). Pediatric postoperative pain was assessed by means of the Wong-Baker Faces Pain Rating Scale (WBFPRS). The testing protocol for the control subjects only differed in that they did not receive an intervention, whereas the assessments remained the same (except for the Likert scale; Figure 1).

Figure 1. Study design flowchart. STAI: State-Trait Anxiety Inventory; mYPAS: modified Yale Preoperative Anxiety Scale; WBFPRS: Wong-Baker Faces Pain Rating Scale.



Participants

A total of 32 children were contacted for inclusion in the study from March to April 2016 from 2 centers in Belgium. Every other week the subjects were included in either the test group or the control group. Eligible participants and their parents for the test group were recruited 2 days before surgery through patient lists of scheduled operations in the surgical day center of RZ Tienen or Medisch Centrum Aarschot in consultation with the doctors. Two days before surgery, parents were contacted by telephone and invited to participate with their child in the study. If they were interested in participation, an email was sent with a link to the CliniPup game. Parents were asked to play the game together with their child. Study information for the parent and child and consent and assent papers were sent via email.

Participants in the control group were recruited at the hospital prior to surgery. Inclusion criteria were (1) aged 6 to 10 years, (2) parents have signed an informed consent, (3) children have given assent, and (4) children and parents understand and speak the Dutch language. Exclusion criteria were (1) children who have been diagnosed with a mental illness, (2) children who have been diagnosed with a developmental delay, (3) children who have a history of an affective disorder, and (4) children with an American Society of Anesthesiology physical status greater than II.

Written informed consent was obtained from 20 parents and assent from 20 children included in the study. The Medical Ethics Committees of UZ Leuven, KU Leuven, and RZ Tienen in Belgium approved all study procedures in advance (study number S58541).

Interventions

The test group accessed CliniPup online and played at home 2 days prior to surgery, and the control group received no intervention (ie, received standard of care).

Outcomes

Primary Outcomes

Preoperative Anxiety

After registration and admission at the hospital, study information was explained to the parent and the child. After signing the consent and assent papers, the preoperative anxiety of the child was measured by the researcher using the mYPAS. The mYPAS is a validated structural observational scale consisting of 27 items in 5 domains (activity, vocalizations, emotional expressivity, state of arousal, and use of parent) of behavior indicating anxiety in young children [25]. After the assessment, a total adjusted score ([activity score/4 + vocalizations score/4 + emotional expressivity score/4 + state of arousal/4 + use of parent score/4] * 100/5) was calculated [25].

Aligned with the institution guidelines, some of the children were given premedication. However, assessment of preoperative anxiety was always completed before the administration of the premedication.

Postoperative Pain

Children were asked to scale their pain using the WBFPRS once they were awake and responsive (15 minutes after they were back in their room). The WBFPRS is used to assess pain in children and help them communicate about it [26]. The WBFPRS, which is an auto-evaluation scale, has six faces representing no pain (0) to worst pain ever (5) [27].

Secondary Outcomes

Parental Preoperative Anxiety

After signing the consent and assent papers, parental anxiety was assessed with the STAI, a widely used self-report anxiety-assessment instrument [28]. There are 2 subscales: State Anxiety Scale and Trait Anxiety Scale. The State Anxiety Scale evaluates the current state of anxiety using items that measure feelings of apprehension, nervousness, tension, worry, and so on. The Trait Anxiety Scale evaluates relatively stable aspects of anxiety including general states confidence, calmness, and security. A total STAI score can be calculated by adding all scores. For the anxiety-absent items, the scores should be reversed (19 items of the total 40) [29].

User Experience and Satisfaction

In the case of the test group, user experience and satisfaction was also assessed through a questionnaire where parents and children completed a Likert scale for each question. Additionally, parents were asked to what extent they would recommend CliniPup to peers, and a net promoter score (NPS) was calculated [30].

Statistical Analysis

A descriptive analysis was performed on the results. No formal power calculation was used. In addition, the children were divided in this study into 2 groups, a test group and a control group. A Fisher exact test was used to assess if gender, previous surgery, and the use of premedication were significantly different between the two groups. Additionally, a Wilcoxon rank-sum test (a nonparametric analogue of the *t* test for two independent samples) was performed to test if the distribution of age was the same across both groups. An independent *t* test was used to determine if there were significant differences in parental anxiety scores between the two groups. A Mann-Whitney U test was used to determine if the preoperative anxiety scores and the postoperative pain scores differed significantly between the control and test group. All statistical analyses were performed using SPSS version 23.0 statistical software (IBM Corp) and were 2-sided with a level of significance of .05.

Results

Patient Flow

Every child aged between 6 and 10 years who met the inclusion criteria was invited to enter the study. In total, 32 children were contacted. After exclusions due to language barriers and no interest in participation, 20 children were recruited. Twelve children were included in the test group and 8 in the control group. In the test group, 8 children were scheduled for tympanostomy tube placement, 2 for adenoidectomy, and 2 for narcodontia (dental care that takes place under general anesthesia). In the control group, 3 children were scheduled for tympanostomy tube placement, 3 for narcodontia, 1 for adenoidectomy, and 1 for adenoidectomy in combination with tympanostomy tube placement (Figure 2).

Baseline Characteristics

Baseline characteristics of study participants are shown in Table 1. There were no significant differences in age, gender, premedication use, and previous surgery experience between the two groups. The distribution of age and gender was the same across the two groups.

Primary Outcomes

Preoperative Anxiety

The researchers measured preoperative anxiety in study participants with the mYPAS observational scale. The mean total adjusted mYPAS score showed a significant difference between the control group and test group (51.88 [SD 15.57] vs 31.67 [SD 7.79], respectively; *P*=.01; Figure 3). This demonstrated that children who played CliniPup before surgery were less anxious than children who did not play CliniPup. No significant correlation was found between the number of times children played CliniPup (1.83 [SD 1.03]) and the total adjusted mYPAS score.

Figure 2. Patient flow diagram.

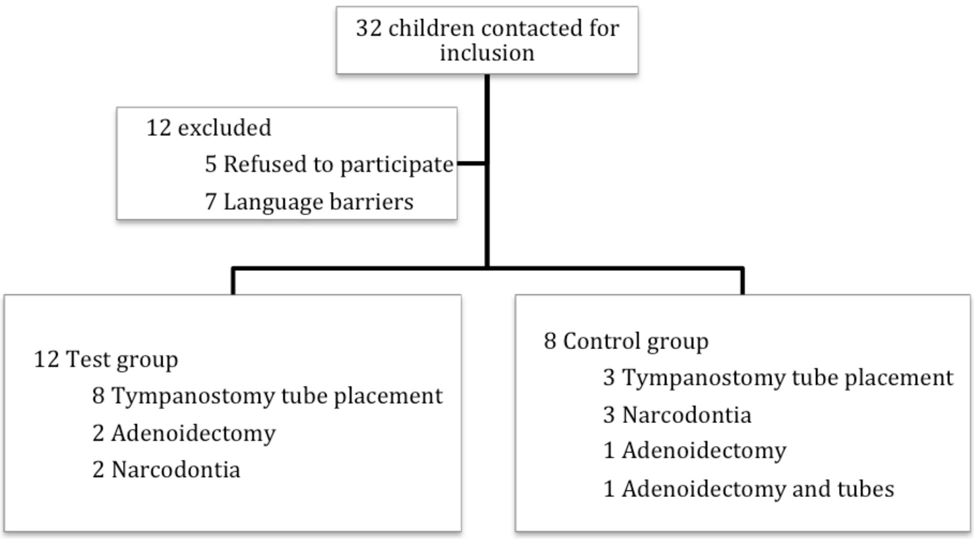
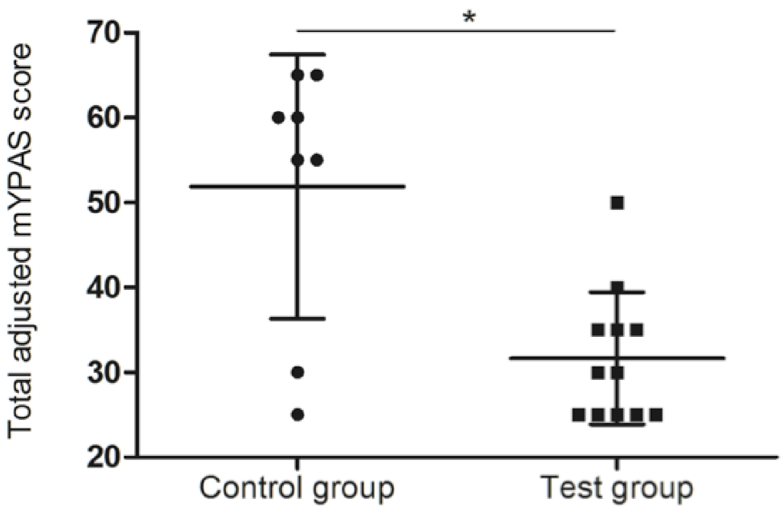


Table 1. Baseline study participant characteristics.

Child characteristic	Control group (n=8)	Test group (n=12)	*P* value
Age in years, mean (SD)	6.87 (0.93)	7.49 (1.82)	.52
Gender, male, n (%)	3 (38)	6 (50)	.67
Previous surgery, yes, n (%)	2 (25)	9 (75)	.07
Premedication with midazolam, yes, n (%)	5 (63)	2 (17)	.06
Number of times CliniPup was played, mean (SD)	—[a]	1.83 (1.03)	—
Surgery type, n (%)			
Tympanostomy tube placement	3 (38)	8 (67)	—
Adenoidectomy	1 (13)	2 (17)	—
Narcodontia	3 (38)	2 (17)	—
Adenoidectomy and tubes	1 (13)	0 (0)	—

[a]Not applicable.

Figure 3. Child preoperative anxiety. mYPAS: modified Yale Preoperative Anxiety Scale.



Postoperative Pain

Postoperative pain in study participants was measured with the WBFPRS scale 15 minutes postoperatively. No significant differences were shown in the analysis of the postoperative pain scores between the control and test group (3.50 [SD 2.77] vs 4.18 [SD 2.33], respectively; *P*=.54; Figure 4).

Secondary Outcomes

Parental Preoperative Anxiety

Parental preoperative anxiety was measured with the STAI completed by the parent before surgery. No significant difference was found between the control group and test group (41.13 [SD 7.70] vs 34.09 [SD 10.00], respectively; *P*=.10; Figure 5).

User Experience and Satisfaction

Children

To evaluate CliniPup, we asked children to complete a Likert scale questionnaire. Sixty-seven percent (8/12) of children liked CliniPup very much, 17% (2/12) of children liked CliniPup at least somewhat, and 17% (2/12) were undecided. Children were also asked if they learned anything by playing CliniPup. Forty-two percent (5/12) learned very much, 33% (4/12) learned somewhat, 20% (2/12) were undecided, and 8% (1/12) learned nothing at all. In summary, 75% (9/12) of children learned somewhat or very much from playing CliniPup.

Parents

One parent of each child (the parent who played CliniPup together with their child) completed the Likert scale questionnaire and provided information on the extent with which they would recommend CliniPup to peers.

Figure 4. Child postoperative pain. WBFPR: Wong-Baker Faces Pain Rating Scale.

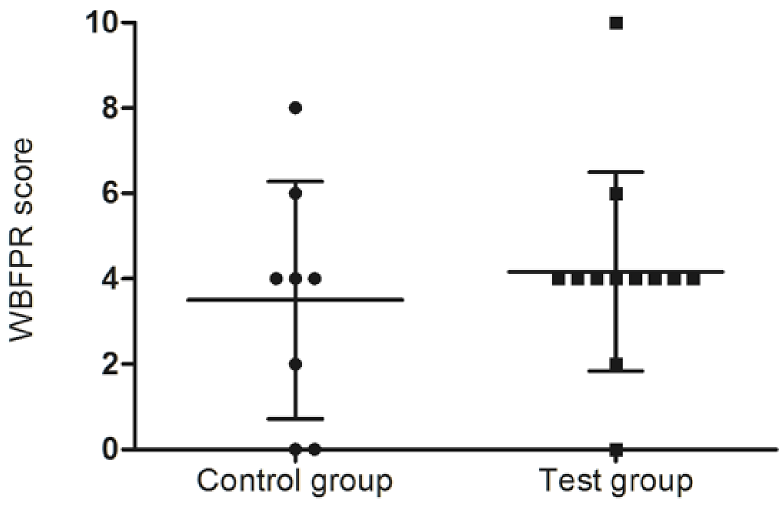
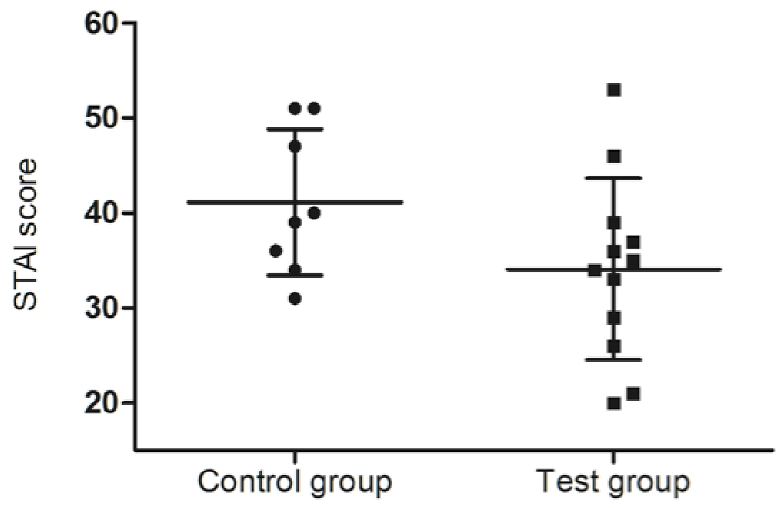


Figure 5. Parental preoperative anxiety. STAI: State-Trait Anxiety Inventory.



Eighty-three percent (9/12) of the parents strongly agreed that "CliniPup was clear; my child understood everything." Fifty-eight percent (7/12) of parents strongly agreed and 42% (5/12) agreed that "CliniPup helped to prepare my child for surgery." Forty-two percent (5/12) of parents strongly agreed and 50% (6/12) agreed that "I received useful information by playing CliniPup together." Additionally, 42% (5/12) disagreed, and 25% (3/12) strongly disagreed that "I had to give additional information to my child." Lastly, 17% (2/12) strongly agreed, 33% (4/12) agreed, and 50% (6/12) did not disagree nor agree that they would like something similar to prepare themselves for the surgery of their children.

When asked on a scale from 0 to 10 (very unlikely to very likely) to what extent they would recommend CliniPup to their friends/family/colleagues, 42% (5/12) of parents gave a 10, 25% (3/12) gave a 9, 17% (2/12) gave an 8, and 17% (2/12) gave a 7. These results correspond to an NPS of 67%.

Discussion

Principal Findings

The findings of this pilot study suggest that the use of CliniPup, an SGH, may be an effective adjuvant intervention to contemporary management of perioperative anxiety and pain in children undergoing ambulatory surgery and their parents. The results of the pilot trial showed that the test group experienced significantly less preoperative anxiety, as measured by the mYPAS scale, than the control group (Figure 3). In contrast, there were no between-group differences in postoperative pain, as measured by WBFPRS, immediately (15 minutes) after surgery (Figure 4). This was not surprising given that operations (tympanostomy tube placement, adenoidectomy, narcodontia, and adenoidectomy in combination with tube placement) were unequally distributed between the groups. This makes it difficult for a fair and representative comparison of postoperative pain scores between groups.

Considering the secondary outcomes, parents of children in the test group experienced equivalent, with a trend toward reduced, preoperative anxiety compared to parents of children in the control group (Figure 5). In addition to the clinical outcomes, the study determined that the majority of children enjoyed playing CliniPup very much and learned a lot by playing CliniPup. Parents agreed with this sentiment as the majority agreed that CliniPup helped their child prepare for surgery. Moreover, CliniPup's NPS was considered excellent, demonstrating that parents were likely to recommend this nonpharmacological intervention to others.

By alleviating anxiety in the home setting prior to surgery, this SGH may address challenges associated with current nonpharmacological interventions such as cost, time requirements, and accessibility and availability [7,9,10]. This may, in turn, reduce the long-term psychosocial burden experienced by children with perioperative anxiety and pain [2,24,31,32]. CliniPup may also offer the potential to improve economic outcomes by reducing medical resource use and decreasing hospital discharge times [2,24,31-33]. However, this would require more targeted research to confirm.

CliniPup shows the potential to address the unmet need of children in the perioperative setting by offering an effective, inexpensive, accessible, and evidence-based nonpharmacological intervention to reduce perioperative anxiety and pain in children.

The data collected within this pilot trial support the conclusion that an SGH, when developed using a scientific methodology such as the SERES Framework, may be particularly valuable as an intervention to educate and change behavior in health care settings [34]. This may be particularly true for a pediatric population, but the generalizability of the approach implemented also suggests that this method could be applicable in adult populations as well. In addition, it is conceivable that similar interventions could be developed to realize behavior change and impact health outcomes in other fields such as mental health, rare disease, cardiovascular health, oncology, etc.

The results collected in this pilot trial serve as important inputs to be used in subsequent iterations of the SGH. This was, in particular, one of the key objectives of the pilot trial, in that the findings will be used to inform the next steps of trial design and game development.

Limitations

The results of this study, however, should be considered as preliminary due to the small sample size and methodological limitations (block randomization, nonblind, inactive control group, two study centers, child and surgical characteristics not controlled for, etc) of a pilot trial. Although the findings of this pilot study are promising, further research is required to validate CliniPup's efficacy in a pivotal trial that is adequately powered to detect between group differences. Additionally, it may be prudent to include an active control and further control for child and surgical characteristics to limit potential methodological biases. Moreover, it may be valuable to investigate the mechanistic bases for the observed changes in perioperative anxiety, which may differ from hypothesized theories and could inform clinical practice. Finally, methodological changes or adaptations to the SGH CliniPup should be considered to enhance the potential for addressing postoperative pain in addition to preoperative anxiety. For example, it is logical to theorize that the addition of a supplementary digital tool targeted at parents of children undergoing ambulatory surgery could improve outcomes, as this would explicitly address parental fears, a key determinant of child pain and anxiety [23]. Such a tool has subsequently been developed, and methodological modifications will be integrated into an upcoming pivotal study to also evaluate (behavioral) changes in postoperative pain management at home.

Conclusion

In summary, the results of the pilot study introduce CliniPup as a potentially effective and attractive adjunct therapy to existing interventions aimed at reducing preoperative anxiety in children undergoing ambulatory surgery. The findings also support the validity of the SERES framework for SGH development with respect to achieving positive health outcomes. The results provide important data to inform subsequent development of the SGH and its future clinical validation. Moreover, based on theories applied in the development of the SGH, supplemental components can be integrated to enhance CliniPup's impact on pediatric perioperative anxiety and pain outcomes. Aligned with this, CliniPup's safety and efficacy should be evaluated further in a pivotal trial of the optimized SGH.

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Conflicts of Interest

SV is a paid consultant for MindBytes, GVS is the founder and CEO of MindBytes and MindLab Interactive AI Inc, and CB is an employee of MindLab Interactive AI Inc and previously served as a paid consultant for MindBytes. JVA, AMB, JT, and KA declare no competing financial interests.

Editorial Notice: This randomized study was only retrospectively registered. The editor granted an exception of ICMJE rules for prospective registration of randomized trials because the risk of bias appears low and the study was considered formative.

However, readers are advised to carefully assess the validity of any potential explicit or implicit claims related to primary outcomes or effectiveness, as retrospective registration does not prevent authors from changing their outcome measures retrospectively.

Multimedia Appendix 1

CONSORT‐EHEALTH checklist (V 1.6.1).

[PDF File (Adobe PDF File), 598KB - games_v7i2e12431_app1.pdf]

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Abbreviations

mYPAS: modified Yale Preoperative Anxiety Scale
NPS: net promoter score
SGH: serious game for health
STAI: State-Trait Anxiety Inventory
WBFPRS: Wong-Baker Faces Pain Rating Scale

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Original Paper

A Badge Design Framework for a Gamified Learning Environment: Cases Analysis and Literature Review for Badge Design

Sungjin Park[1*], MEng; Sangkyun Kim[1*], PhD

Management of Technology Lab, Kangwon National University, Chuncheon, Republic of Korea

[*]all authors contributed equally

Corresponding Author:
Sangkyun Kim, PhD
Management of Technology Lab
Kangwon National University
417, Engineering Building 1
Kangwon Daehak GIl 1
Chuncheon,
Republic of Korea
Phone: 82 033 250 6287
Email: saviour@kangwon.ac.kr

Abstract

Background: In the past, the educational badge was an extrinsic means of rewarding the motivation to learn. Based on continued research, however, the badge began to be recognized as a scale to measure the learner's knowledge and skill and an important means of helping learners to gradually build intrinsic motivation by using certain extrinsic motivators. As the badge's value has grown, the importance of its design has garnered attention.

Objective: The objective of this research was to establish a badge design framework that can be used in a gamified learning environment.

Methods: Data were collected from previous studies on badge design, 943 badge cases were extracted from 11 online and offline gamification in education contents, and their patterns and features were analyzed.

Results: Based on the analysis of results from previous studies and 943 collected badge cases, our study suggests three conditions for badge design. Through the literature review and collected badge cases, our study designed a badge design framework. First, it is necessary to distinguish whether the type of learning activity required for earning badges is physical or conceptual. Second, it is necessary to distinguish whether the scale of an activity required for earning badges requires individual learning or interaction-induced learning. Third, it is important to review whether the time and effort invested in earning badges is simple, repetitive, and short-term or continuous and long-term. Based on these three conditions, collected badge cases were analyzed. To verify self-developed badge types, we conducted a chi-square test on the collected cases and confirmed that there was a significant difference for each of the eight badge types (Pearson chi-square 1117.7, *P*<.001).

Conclusions: Through its literature review on previous studies, this study demonstrated the badge's educational effectiveness. The badge design framework suggested in our study is expected to resolve some of the difficulties experienced during the badge design process in a gamified learning environment, encourage efficient badge design, and maximize learning effect.

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KEYWORDS

badge design framework; educational badge; digital badge; badge types; gamified learning environment

Introduction

Gamification and Digital Badges

Gamification in education applies game elements to an educational context [1]. Through game mechanics such as badges, leaderboards, and avatars, feedback is provided to the learner and encourages collaboration and cooperation [2,3]. In the education context, gamification has been touted to overcome the shortcomings of traditional learning methods; it has been claimed that it could offer learners new experiences and values [4]. Before gamification, educational games, game-based learning, and serious games were applied to the classroom. Since gamification was defined, however, it has become preferred among instructors compared with the other techniques (Figures 1 and 2). Al-Azawi et al [5] compared gamification, game-based learning, and educational gaming. We analyzed the benefits of gamification in these same contexts. The contexts are provided below along with their respective advantages:

- Gamification in education: better learning experience, better learning environment, instant feedback, better prompting of behavioral change, and better applicability in terms of most learning needs compared with game-based learning and educational games
- Game-based learning: increases learner's memory capacity and computer and simulation fluency, helps to quicken strategic thinking and problem solving, develops hand-eye coordination, and facilitates skill-building
- Educational gaming: improves motor skills, social development, focus and memory ability, self-esteem, and creativity

As interest in online learning environments has grown greatly, so has interest in digital badges. We conducted a keyword search for digital badges in Google Trends. The results showed that its search trend has been on the rise since 2010 (Figure 3); furthermore, terms related to the education context were found to be related search words (Figure 4). Badges, which were once used as mere extrinsic rewards, were actively used in the gamified learning environment.

The badge is a product of the learner's invested time and efforts; furthermore, it functions as a scale that indirectly indicates one's ability level to others [6]. It can be applied in both online and offline education environments. From a pedagogical viewpoint, the use of badges can help to introduce innovation to the education environment and thus have a positive effect on promoting learning achievements [7]. For this reason, the process of designing a badge is important. Most badges are designed based on the experiential judgment of the designer, teacher, or decision maker. Designing a badge based on the relevant theoretical background, evidence from previous cases, and the designer's experience, however, makes the badge more efficient for use. Therefore, in this study we looked into previous research, collected 943 badges from 11 online and offline educational sources, and analyzed their patterns and features in order to determine an efficient badge design.

Figure 1. Keyword search results in Google Trend (blue: gamification, red: game-based learning, yellow: serious game, green: educational game). The x-axis is time from 2004 to April 11, 2019. The y-axis is the search volume provided by Google Trends and range is 0 to 100.

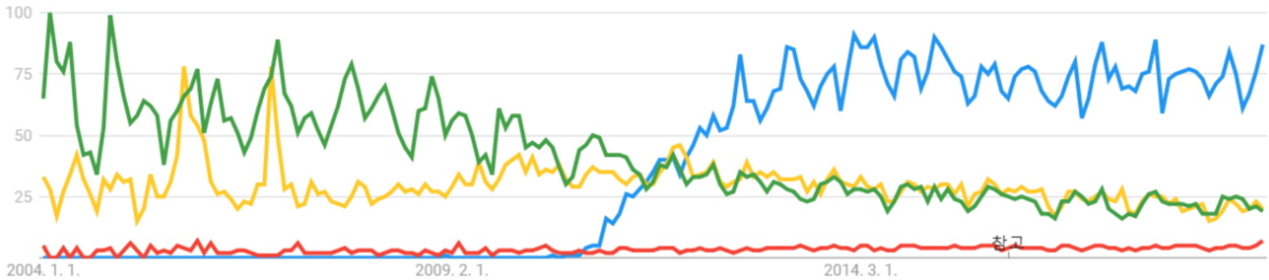


Figure 2. Regional interest by country in Google Trends from 2004 to April 11, 2019 (deeper color indicates more interest).

Figure 3. Interest in digital badges as shown in Google Trends. The x-axis is time from 2004 to April 11, 2019. The y-axis is the search volume provided by Google Trends and range is 0 to 100.

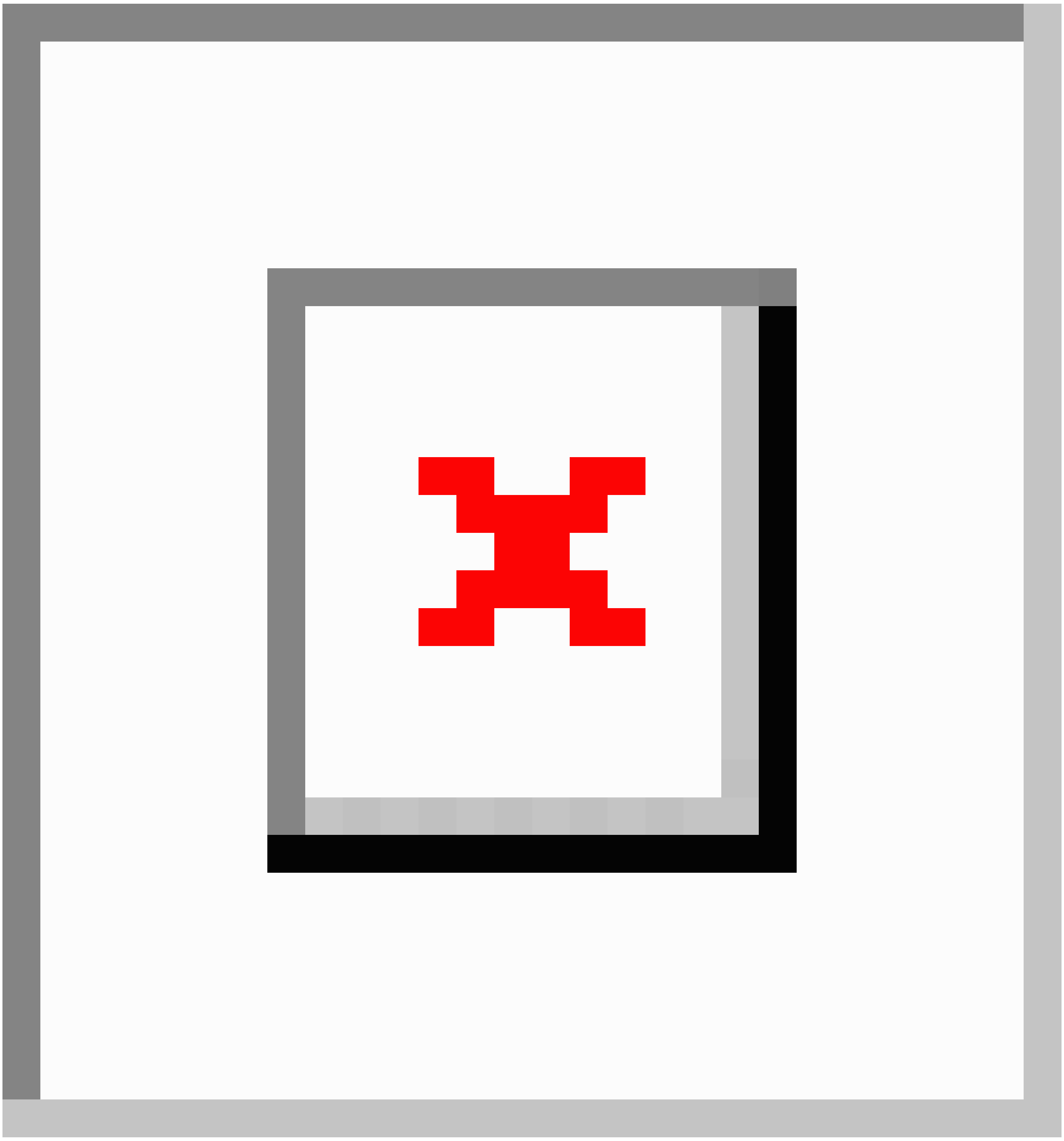
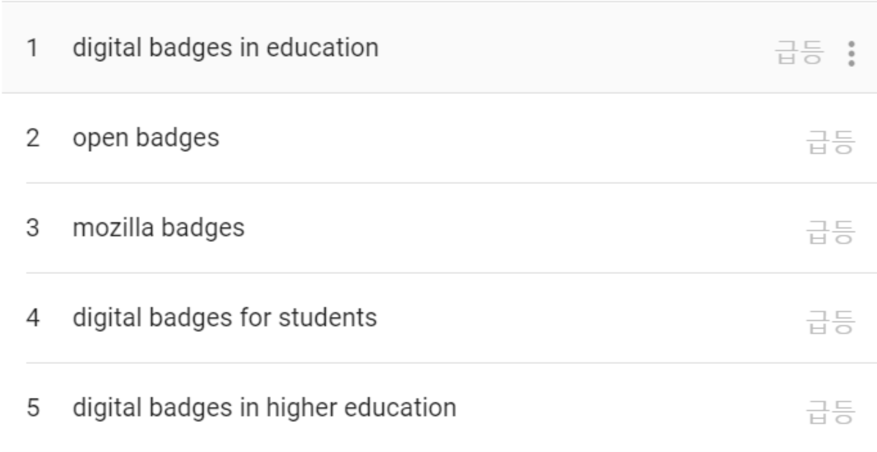


Figure 4. Google Trends keyword search result related to digital badges.



Background and Literature Review

Al-Azawi et al [5] point out the differences between gamification and the two previously mentioned techniques of game-based learning and educational games in terms of the implementation method, cost, and applicability. While gamification is affordable in terms of development and easier to implement, the teacher may find it hard to access the other two techniques of game-based learning and educational games, since they should be developed like actual video games using computer or console game such as PlayStation (Sony Interactive Entertainment LLC) or Xbox (Microsoft Corp). In addition, these techniques tend to be expensive in terms of development.

It was suggested that gamification in education can deliver a gameful experience in the education environment through game design elements, facilitate the learner's use of game-like thinking and strategies, and provide an immersive learning experience. De Sousa Borges et al [8] conducted a systematic mapping review of 357 previous studies related to gamification in education. The review established seven categories that could be used to analyze such studies. Based on the results, the review suggested that the learning environment could be improved and learning performance enhanced through the following seven features in gamification in education:

- Mastering skills: enhance or improve the learner's ability through complex and repeated activities that use gamification in education
- Challenge: aid the learner in actively participating in learning activities to improve their learning
- Guidelines: provide the theoretical background that helps with gamification settings in the education context
- Engagement: maintain or promote the learner's interests in learning activities
- Learning improvement: reinforce the learner's learning activities through a gamified solution and maximize the outcomes of the learning process
- Behavioral change: encourage and facilitate changes in the learner's behaviors through the gamified system
- Socialization: provide an efficient learning behavioral change through the gamification for social activities such as communication and decision-making

Gamification in education contexts can also induce affordance in terms of learning. Majuri et al [9] conducted an empirical study on previous studies related to gamification in education. Out of 807 previous studies related to the research topic, the study selected 128. Analysis of these 128 previous studies showed that gamification in education could induce affordance; have a significant effect on psychological factors such as improved cognitive function, immersion, fun, and engagement; and change and encourage behaviors.

Gamification in education helped to introduce innovation into the education environment by providing many benefits to the learner. As gamification began to be applied into the education environment, many different game mechanics began to be used. Dicheva et al [10] carried out a systematic mapping review of previous gamification in education studies that had been conducted between 2010 and 2014. This review revealed that the highest number of previous studies on gamification in education had been conducted in 2013; in these studies, gamification was used to indicate learning status and improve social engagement. Furthermore, they found that the game mechanics were most used in the order of badge, leaderboard, point, level, virtual goods, and avatars. Of the 754 gamification cases analyzed by Park and Kim [11], 127 were related to gamification in education. In 73 of these cases (57.5%), badges were applied to learning behavior. Recently, gamification has begun to be applied to online learning platforms, and studies are being actively conducted on the digital badges applicable to the online learning environment. Gibson et al [6] stated that when digital badges are used in the education environment, it is possible to establish an affordance-based learning environment, motivate learning through the use of badges, and self-check one's learning status; thus, affordance is expected to work to encourage the learner to reach their goals by representing invisible learning achievements as visible ones. McIlvenny [12] suggested that information for such badges should include badge icon, issuer, issue data, badge details, badge criteria, and evidence when disclosing the badges. Based on five identifiable items out of these six, we collected badge cases.

Methods

Data Collection

To collect badge cases, Google search was used and previous studies and related books were reviewed. The cases were collected from Dec 1, 2018, to January 31, 2019. The search keywords were badge in gamification, badge example in gamified learning (classroom), educational badges, and (gamification in education contents names) badges examples. The collected cases were summarized and arranged in Excel 2013 (Microsoft Corp). The study referred to six types of digital badge metadata that were suggested by McIlvenny [12] for badge information.

To make a badge design framework, we considered the mutually exclusive collectively exhaustive (MECE) approach. Compared with previous studies, we have minimized the weaknesses of self-developed badge design framework considering MECE. To verify a self-developed badge design framework, we conducted a Pearson chi-square test using SPSS Statistics version 23 (IBM Corp).

To present an efficient badge design framework, we collected 943 badge cases from 11 online and offline gamification in education contents that used badges and were available to the public. Table 1 provides information on the collected badges.

Codecademy [13], Codecombat [14], Khan Academy [20], and Sololearn [25] are gamification in education platforms that provide contents related to computer language learning. Duolingo [15] is a gamification in education platform for language learning. Codecademy (forum) [13] and Memrise (forum) [21] are online community platforms that were created for sharing user’s opinions; they use badges to encourage and promote activities in their communities. Edge [18] is a gamified customer relationship management system that manages customer loyalty based on the point, badge, and leaderboard/level system [26]. Fitbit [19] and Nike Plus [22] manage the amount of exercise accomplished by users based on mobile apps and hardware. Pokemon Go [24] is a Global Positioning System–based mobile augmented reality (AR) activity app. While it was approached as a game in its early days, Althoff et al [27] recognized Pokemon Go as gamified content, since it positively contributes to increasing physical activities. Thus, it was included as one of the cases in this study. Passport to Success [23] is a badge that is used for improving learning motivation and behavioral changes in schools located in the Corona-Norco Unified School District, California, United States.

In these cases, the time periods required to earn badges were calculated in terms of the number of days. The time periods used in the cases, on a minute or hour basis, were converted into decimals based on a period of 24 hours (one day). In the collected cases, the unit used to measure physical activities, such as walking, running, and walking upstairs, was converted into kilometer. We referred to the Kyle’s Converter website [28] in order to convert the number of steps.

Table 1. Introduction of gamification in education for badge collecting.

Gamified learning contents	Category	Type	Badges, n	Reference
Codecademy (forum)	Community	Software (online)	60	[13]
Codecombat	Education	Software (online)	51	[14]
Duolingo	Education	Software (online)	44	[15-17]
Edge	Royalty management	Software (online)	24	[18]
Fitbit	Health care	Software (app + hardware)	62	[19]
Khan Academy	Education	Software (online)	97	[20]
Memrise (forum)	Community	Software (online)	50	[21]
Nike Plus	Health care	Software (app + hardware)	78	[22]
Passport to Success	Education	Print out work + software (online)	300	[23]
Pokemon Go	Health care	Software (app)	123	[24]
Sololearn	Education	Software (online)	54	[25]

The numerical values for the other activities, except the physical ones (eg, solving quizzes, earning likes, and so on), in the collected badge cases were input without conversion:

- Badge name: name of the badge used in learning content
- Application domain: domain of the learning content that applies to a badge
- Reward criteria: activity criteria required for earning a badge
- Activity interval: period of time spent in earning the badge. Recorded on the basis of a day (24 hours) (eg, 5 hours = 0.21 days, 3 weeks = 21 days, 1 year = 365 days)
- Activity amount-1: physical activities (walking, running, and walking upstairs), among others, conducted to earn the badge. Converted into km (eg, 1 mile = 1.61 km, 1 step and 1 stair step = 0.0008 km)
- Activity amount-2: quantitative amount of activities required for earning the badge assigned for the relevant contents, except for badge cases dealing with health care (eg, earned 20 likes = 20, 50 links shared = 50, 30 solved problems = 30)

Badge Design Framework

Figure 5 illustrates a badge design perspective that applies the MECE approach to suggest a badge design framework. The suggested badge design framework consists of three axes.

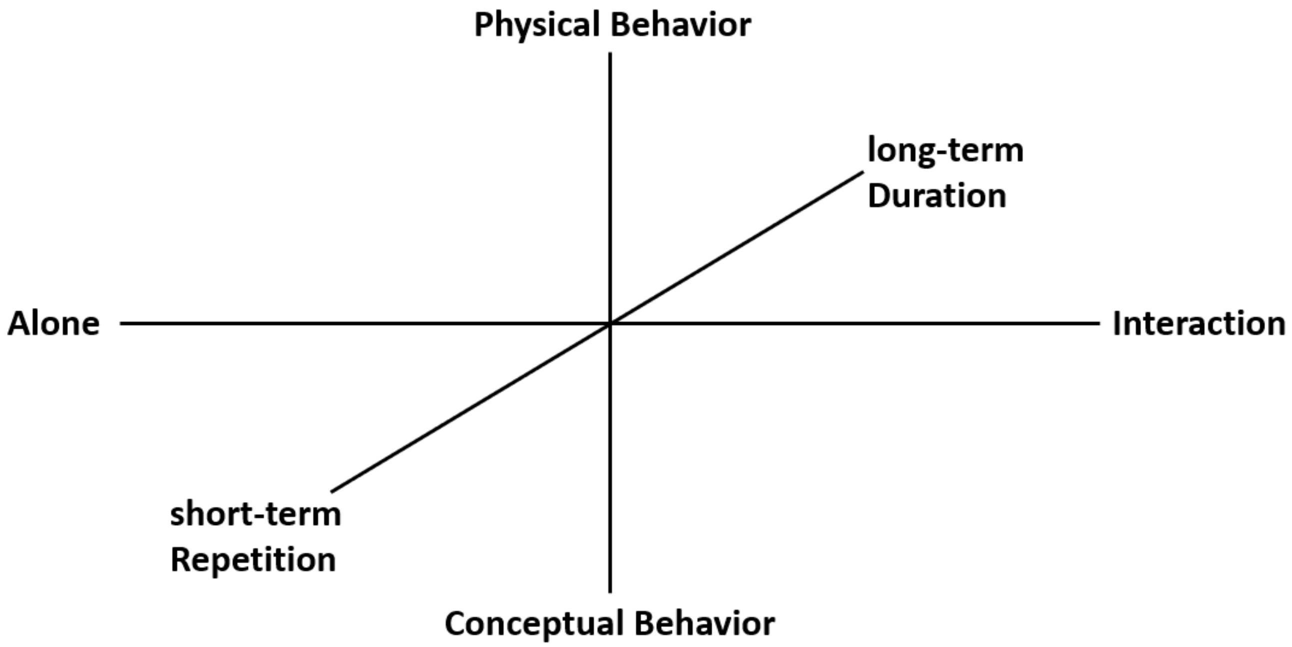
The x-axis indicates the interaction of the player participating in an activity. It is divided in terms of individual activity without interaction between players and activity requiring interaction between players. The y-axis indicates the type of learning activity required for earning a badge. This is categorized into the following types: physical and conceptual. The z-axis indicates the time and effort required for investing in a learning activity in order to earn a badge. It is divided as follows: short-term simple repeated activity and long-term complex difficult activity.

X-Axis: Interaction Between Players to Earn a Badge—Playing Alone Versus Playing Together

To be precise, carrying out a learning activity alone provides a sense of familiarity. In the gamified learning environment, however, interacting with other learners is effective for improving social skills such as communication [29], listening [30], problem solving, and improving learning motivation [31,32]. In the gamified learning environment, an assignment is provided to the learner in the form of a mission/quest based on the learning content. The missions/quests are categorized based on two criteria: one mission/quest that can be solved by an individual alone and another that encourages two or more learners to interact with each other and solve the problem. The learning activity form is determined based on the theoretical background suggested by the x-axis. To ensure affordance for the learner, the y-axis should determine whether an individual completes a learning activity alone or in cooperation with two or more learners.

Among the cases collected by this research team, Passport to Success [23] required the completion of particular courses and encouraged participation in activities (club activities, volunteering, cardiopulmonary resuscitation training, and local events). Cases from online learning platforms encouraged interaction in a way that commonly allowed learners to share the problem they had solved and receive feedback from one or more people; furthermore, it may evaluate the result of n or more people. Meanwhile, the process of learning a specific skill or knowledge was designed to encourage an individual to learn alone and earn a badge if he or she satisfies certain standards.

Figure 5. Suggested badge design framework.



Y-Axis: The Type of Learning Activity Required for Earning a Badge—Physical Versus Conceptual Activities

According to the experiential learning theory developed by Kolb [33], the methods through which the learner acquires experience during the learning process are categorized based on two types: concrete experience and abstract conceptualization; the learner carries out reflective observation and active experimentation based on such experiences. However, the theory suggests that experiential learning is completed only through cyclical repetitions of the above process. Our study relied on Kolb's work to suggest appropriate activity types for earning a badge based on concrete experience and abstract conceptualization, which the learner experiences through the learning process. When the teacher designs a learning activity, the relevant learning experiences are provided through physical and conceptual activities. Physical activities can make the learning experience more concrete. Conceptual activities allow the learner to experience abstract conceptualization. Therefore, activity types that can efficiently deliver learning experiences in the learning environment can be divided into two categories: physical and conceptual.

The teacher considers the physical learning environment while providing efficient learning experiences because the physical learning environment is a major variable that affects academic achievement [34]. According to Caldwell [35], learners who completed a learning activity in an ergonomics-based physical learning environment improved their academic achievement by 26.2% compared with learners in other environments. On the other hand, since excessive promotion of physical learning activities in physical learning environments might have a negative effect on the learner [36], it is important to request an appropriate level of physical learning.

Conceptual learning activity plays an important role in the development of reasoning, categorization, memorization, problem solving, and generalization, which cannot be learned through physical activities [37]. The teacher provides the learner with conceptual learning activities and delivers experiences related to creating and using a concept. Using this method can help the learner move beyond simply categorizing objects based on basic rules or features; this helps the learner experience conceptual learning by finding complex rules and new patterns and conceptualizing them. Through this process, the learner experiences abstract concepts and accepts them as a part of their own learning experience.

Among the cases collected by this research team, physical learning activity cases included learning n or more computer programming skills, uploading n or more posts, and posting n or more mentions. Health care apps included walking n steps or running n km. Conceptual activities included solving quizzes related to the learning content, implementing a more effective algorithm (compared with the existing one), uploading n posts, and posting n mentions. As a special case, Khan Academy [20] did not just deliver badges but also introduced great historical figures in related fields (eg, Benjamin Franklin, Frederick Douglass). Among the collected cases, the minimum amount of activities was 3 [20], while the maximum amount of activities was 1000 [19,23]. In the case of health care apps, the activities were walking 41.84 km (26 miles) [19], 72 km (90,000 steps) [19], and 12,861.88 km (7992 miles) [19] and earning 5000 to 2,000,000 points [22]. Passport to Success [23] implemented a condition where a badge was earned when the learner acquired a certain grade point average (GPA) level for a particular subject, grade, or semester.

Z-Axis: Time and Effort Invested to Earn a Badge—Simple Repeated Short Term Versus Complex Continued Long Term

Using an experiment, Ebbinghaus [38] proved that knowledge acquired through learning could be forgotten over time. Pedagogy has continued to conduct research in order to solve this problem and thus resolve forgotten knowledge by repeating learning as much as it is forgotten. Dale [39] recommended applying participatory learning methods (group discussion, practice, and teaching others) to the cone of experience instead of passive learning methods (listening to lectures, reading, using audio-visual learning materials, and viewing demonstrations) in order to facilitate efficient learning. This is because learning through interaction with other learners or a teacher is more effective for learning new knowledge and skills compared with sitting alone and struggling with the book. In a gamified learning environment, cognitive apprenticeship [1,40] is established, in which the learner receives the teacher's knowledge and skill through interaction with the teacher. On a gamified online learning platform, the learner learns basic knowledge and skills from a tutorial and masters them by applying and expanding them while solving a given problem.

The problem of forgetting easier and simpler knowledge and skills can be solved through short-term repeated learning. In a gamified training environment, the learner can acquire knowledge and skills through simple repetitions [41]. However, this approach does not apply to knowledge or skills that are complex and difficult and thus require long-term training. By using game elements, the gamified learning environment provides continuous learning motivation for gaining knowledge or skills that require continuous and long-term training [31]. Therefore, in cases where a gamified learning environment uses a badge, the teacher should encourage the learner to learn easier and simpler knowledge or skills through short-term/repeated learning and set an appropriate period of learning time; furthermore, the teacher should induce a learning activity to help the learner acquire knowledge or skills that require more complex, difficult, and long-term training.

Of the 943 cases collected by this research team, 306 badge cases offered concrete examples. Taking 1 day as 1440 hours, the average period required to earn a badge was 165.46 days, the minimum was 0.01 days (15 minutes) [20], and the maximum was 1460 days (4 years) [19]. For Passport to Success [23], the predetermined period units were quarter, trimester, and semester. Furthermore, when the specific event was held in a local area that used Passport to Success [23], badge gain condition was set to coincide with the event period. Gamified health care apps set this period on a weekly or monthly basis. The period set for earning badges should be established based on the teacher's experience and knowhow. Academically, there is no equation or theory to calculate the optimal period for earning badges.

Results

Suggestions Regarding Badge Types

This study suggests eight badge types for three badge design conditions (Figure 6). Table 2 describes the characteristics of each type of badge.

Table 3 shows the analysis results for 943 badges from 11 gamification in education contents that were categorized into this research team's badge types. We conducted Pearson chi-square tests, and there was a significant difference of chi-square 1117.7, $P<.001$.

Three patterns were extracted from badge cases collected by this research team. First, online platforms were considered. Badges in Codecademy (forum) [13], Codecombat [14], Duolingo [15-17], Edge [18], Khan Academy [20], Memrise (forum) [21], and Sololearn [25] showed a similar type of distribution. It is conjectured that online platforms focused on conceptual activities, since physical activities are limited online. Among these seven online platforms, the proportion of badges that encouraged interactions with other learners instead of individual learning was higher in Codecademy (forum) [13], Memrise (forum) [21], and Sololearn [25]. It is interpreted that these platforms encouraged the learner to share their learning outcome with other learners, receive feedback from them, and thus expand knowledge. Meanwhile, Codecombat [14], Duolingo [15-17], Edge [18], and Khan Academy [20] provided more badges related to individual learning compared with interaction-related ones. It is reckoned that these online platforms intended to encourage the learner to master knowledge over a long-term period through repeated short-term training.

Second, health care apps were also considered. They included Fitbit [19], Nike Plus [22], and Pokemon Go [24]. These contents all commonly feature exercise. They set concrete criteria for encouraging the user's physical activities, and they increased the distance or the number of necessary steps in order to continue activities. In addition, analysis showed that these health care apps applied badge credentials to the amount of exercise undertaken, which was not very visible; furthermore, they inspired the users to work toward their goals. In the meantime, these contents had a relatively smaller number of badges that encouraged interaction.

Last, Passport to Success [23] was examined. This case was applied to the actual educational setting, and eight types of badges were extracted compared with the other cases. Since it is a learning-related badge, it has been conjectured that its badge distribution is higher among conceptual activities than physical ones. In Passport to Success, however, badges were distributed on a periodic (semester, trimester, and yearly) basis in order to encourage the following physical activities: clubs, bands, and Reserve Officers' Training Corps. For conceptual activities, badges that encouraged the learner to obtain a certain GPA level (B or C, 3.0 or higher, 3.5 or higher, and 4.0 or higher) were arranged on a periodic (semester, trimester, and yearly) basis.

Figure 6. Suggested badge types.

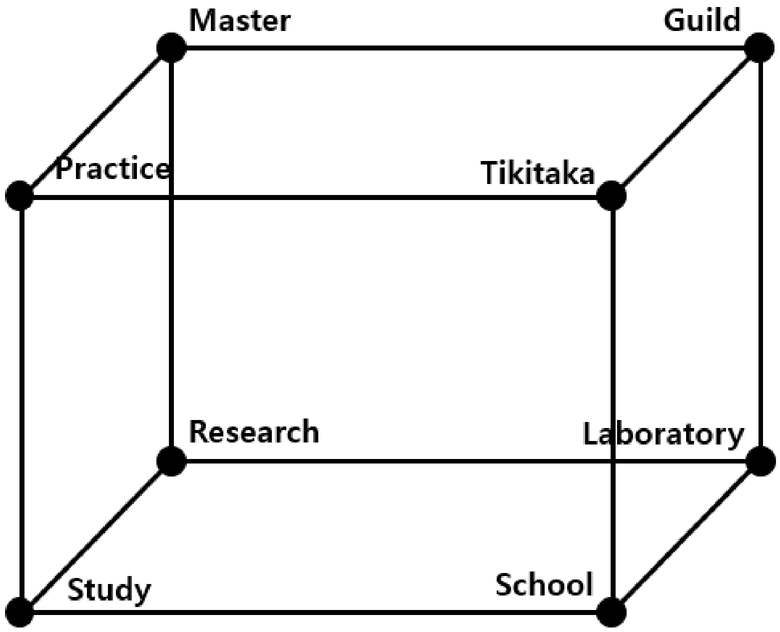


Table 2. Description of badge types.

Type	Framework			Description and goal of badge
	X-axis	Y-axis	Z-axis	
Practice	Physical	Alone	Short-term	• Badge type for a simpler and easier learning activity that should be repeated alone for a short-term period • Badge type that is provided when it is necessary to acquire a lower-level skill in order to learn a higher one
Mastery	Physical	Alone	Long-term	• Badge type for a complex and difficult physical learning activity that should be performed alone for a certain period of time • Badge type provided when a higher-level skill should be refined by using a lower-level one
Tikitaka	Physical	Interaction	Short-term	• Badge type for a simple learning activity that should be repeated with other learners for a short-term period • Badge type provided when a basic skill required for performing the final project in a team activity needs to be learned
Guild	Physical	Interaction	Long-term	• Badge type for a physical learning activity that requires collaboration and cooperation with other learners for a certain period of time • Badge type provided when immersion is needed to produce a final project outcome in a team activity
Study	Conceptual	Alone	Short-term	• Badge type provided for an easier and more repetitive conceptual learning activity (eg, memorizing a simple math equation or studying grammar) • Badge type used when it is necessary to encourage a basic knowledge learning activity to learn a higher-level concept
Research	Conceptual	Alone	Long-term	• Badge type provided for a complex, difficult, and continuous conceptual learning activity (eg, memorizing a calculus equation or learning a difficult algorithm) • Badge type provided when immersion and encouragement are required for a learning activity involving a difficult algorithm or a concept based on a lower-level concept
School	Conceptual	Interaction	Short-term	• Badge type for a learning activity that encourages collaboration and cooperation in order to overcome limitations at an individual level; it can be acquired over a short-term period • Badge type provided for immersion and encouragement in an activity that requires learners to share opinions with one another in order to suggest the final project idea in a team activity
Laboratory	Conceptual	Interaction	Long-term	• Badge type provided for a learning activity that encourages continued collaboration and cooperation in order to perform a long-term project or resolve a particular issue • Badge type provided when it is necessary to encourage each team member to perform his or her role in order to complete the final team activity project

Table 3. The distribution of suggested badge types in collected learning platform cases.

Gamified learning contents	Practice, n (%)	Master, n (%)	Tikitaka, n (%)	Guild, n (%)	Study, n (%)	Research, n (%)	School, n (%)	Laboratory, n (%)
Codecademy (forum)	0 (0)	0 (0)	0 (0)	0 (0)	5 (8)	6 (10)	31 (52)	18 (30)
Codecombat	0 (0)	0 (0)	0 (0)	0 (0)	32 (63)	11 (22)	8 (16)	0 (0)
Duolingo	4 (9)	0 (0)	0 (0)	0 (0)	24 (55)	8 (18)	6 (14)	2 (5)
Edge	0 (0)	0 (0)	0 (0)	0 (0)	4 (17)	2 (8)	1 (4)	17 (71)
Fitbit	29 (47)	33 (53)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Khan Academy	0 (0)	0 (0)	0 (0)	0 (0)	38 (39)	31 (32)	19 (20)	9 (9)
Memrise (forum)	0 (0)	0 (0)	0 (0)	0 (0)	11 (22)	7 (14)	24 (48)	8 (16)
Nike Plus	43 (55)	30 (38)	3 (4)	1 (1)	0 (0)	0 (0)	1 (1)	0 (0)
Passport to Success	6 (2)	13 (4)	17 (6)	12 (4)	120 (40)	57 (19)	44 (15)	31 (10)
Pokemon Go	40 (33)	65 (53)	4 (3)	8 (7)	0 (0)	0 (0)	6 (5)	0 (0)
Sololearn	0 (0)	0 (0)	0 (0)	0 (0)	5 (9)	8 (15)	25 (46)	16 (30)

Discussion

Principal Findings

Our study describes a badge design framework for improving the learner's learning motivation in a gamified learning environment and for introducing innovation into the learning environment. In past educational settings, the badge was simply an extrinsic reward; however, it has now become one of the devices that induces affordance toward self-directed learning by improving learning sustainability, providing learning motivation, and setting goals. Furthermore, badges have begun to be recognized as microcredentials. Mozilla's Open Badge is one good example that indicates this trend. Open Badges are applied to online learning platforms, and the credentials that the learner has acquired are provided in the form of badges. The provided badge can be indicated on the learner's social network services such as Facebook and LinkedIn. It is acknowledged as the learner's acquired badge, even though the learner does not include it in his or her résumé or submit a copy of this credential. As such, the applicability of such badges is expanding gradually.

Therefore, a badge design should be more systematic. In addition to Open Badges, the badge application system provides a badge design tool that can create a badge by inputting an icon, a badge name, a description, and a completion date. However, creating a badge-specific design in order to encourage the learner's affordance is ultimately up to the teacher or designer.

Devedžić [42] analyzed the advantages of a badge from the perspectives of the learner and the teacher. The learner-centered perspective suggests that badges offer the following benefits: flexibility in the learning environment through the use of badges, voluntary setting of learner goals, visualization of previously completed goals, progress in terms of gaining learning experience, and provision of the possibility to plan and implement a future learning activity. Furthermore, it was revealed that the badge had a positive effect on critical thinking, teamwork, leadership, and abilities or skills/knowledge that had not been recognized properly. Devedžić [42] made suggestions for efficiently reflecting a badge's characteristics from the perspectives of the learner, the teacher, and the educational institution as follows.

From the learner's perspective:

- Supporting goal setting, planning, and self-reflection
- Feedback provision through abstraction and integration of learning traces from various learning environments
- Recognition of otherwise underrecognized or nonrecognized skills and prior learning
- Development of a sense of community membership

From the teacher's perspective:

- Facilitating learners' motivation and engagement
- Scaffolding the learning process: using badges to chart learning routes for students
- Supporting alternative assessments and feedback provision

From the educational institution's perspective:

- Improvement of assessment, grading, and feedback collection
- Increased visibility and interschool collaboration and cooperation
- Improvements in instructional and motivational practices

In order to incorporate the above values suggested by Devedžić [29], it is necessary to use the badge design framework developed in this study. Badges designed by using our study's badge design framework are expected to efficiently deliver the aforementioned seven benefits to the learner. This paper still recommends that users use the existing tool to create a basic badge structure or McIlvenny's [12] suggested basic badge structure. However, if the three conditions for a badge design framework, as suggested by this research team, are used to encourage the learner's affordance through badges, it is expected to enable an efficient badge design that can facilitate a learning activity that the teacher wants to conduct.

Limitations

The following are the limitations and future directions of this study. It is necessary to ensure feasibility by categorizing badges that are actually used in educational settings based on this study's badge design framework. Since this study developed the framework based on 943 collected cases, it is estimated that it might be difficult to test feasibility based on these collected cases. Therefore, it is necessary to conduct a follow-up study to test this research team's developed badge design framework. Furthermore, it is necessary to test the effectiveness of badges developed through use of this research team's badge framework. The basic badge structure can be developed based on previous studies. An additional study should be conducted in order to develop the features that will be included in the badges based on the findings of this study and test whether they are effective in practical terms. To test efficiency in the education environment, it is necessary to conduct a follow-up study by using the existing questionnaire tool. Glynn et al [43] developed the Science Motivation Questionnaire II, which ensured the validity and reliability of this study through statistical tests. The questionnaire tool includes items related to intrinsic motivation, career motivation, self-determination, self-efficacy, and grade motivation. A future study will use this questionnaire tool, design badges using this research team's developed badge design framework, and analyze their efficiency in actual educational settings.

Conclusions

Based on our research, we recommend that users design a badge in a way that the eight types of badges are distributed evenly. In the online learning environment, physical learning activities are limited in practical terms. The dual process theory describes a system in which people receive and process information [1]. System 1 uses five senses; alternatively, it can carry out parallel processing automatically and emotionally to acquire new information. System 2 processes new information in a controlled and analytical manner based on a particular set of principles or rules. Usually, people first acquire new knowledge from system 2 and then internalize it in a way that best suits them by using system 1. If physical and conceptual learning activities are balanced based on the previously mentioned information processing mechanisms, the efficiency of learning can be maximized. While it is good to use a badge to learn a particular concept or theory, we suggest that badges should be designed evenly based on our suggested badge design framework; this will help to strike a balance between physical and conceptual activities. Among the badge cases collected by this research team, all the cases (except for Passport to Success) showed a concentrated distribution toward the content's domain. While there might be a limitation in providing all activities, badges should be designed so that they induce interaction to overcome individual learning limitations, thus encouraging balanced activities.

Acknowledgments

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Conflicts of Interest

None declared.

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Abbreviations

GPA: grade point average
MECE: mutually exclusive collectively exhaustive

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Original Paper

Acceptability of a Plasticity-Focused Serious Game Intervention for Posttraumatic Stress Disorder: User Requirements Analysis

Matthew Jones[1], BSc, MSc, Post Grad Dip; Alena Denisova[2], BSc, PhD; Stephen Mitchell[2], BSc, PgCert, MSc; Tom Owen[2], BSc, PhD

[1]Health Services Research, Medical School, Swansea University, Swansea, United Kingdom

[2]Department of Computer Science, College of Science, Swansea University, Swansea, United Kingdom

Corresponding Author:
Matthew Jones, BSc, MSc, Post Grad Dip
Health Services Research
Medical School
Swansea University
ILS 2, Swansea University Medical School
Singleton Park Campus
Swansea,
United Kingdom
Phone: 44 01792513409
Email: m.b.jones@swansea.ac.uk

Abstract

Background: Trauma-focused cognitive behavioral therapy (TF-CBT) is a first-line treatment for posttraumatic stress disorder (PTSD). Despite a solid evidence base, TF-CBT response and attrition rates vary considerably. Plasticity-focused interventions, including the use of serious games, have the potential to improve TF-CBT response and treatment retention.

Objective: The aim of this study was to assess the acceptability of a mobile phone–delivered plasticity-focused serious game to improve response to TF-CBT for PTSD, and carry out a user requirements analysis should the development of a prototype be warranted.

Methods: We conducted 2 one-to-one interviews (n=2), one focus group involving service users who had received a diagnosis of PTSD (n=3) and one focus group involving psychological trauma service clinicians (n=4).

Results: We found that the concept of a plasticity-focused mobile phone intervention for PTSD is acceptable to patients and clinicians. Service users and clinicians both believed that the usage should be guided by a therapist, and both contributed useful inputs regarding the audiovisual aspects of the proposed serious game. It was accepted that the game would not be suitable for all patients and that clinicians would need to appropriately prescribe the usage of the game.

Conclusions: The findings highlight the acceptability of the proposed serious game and clarify the user requirements for such an intervention. It is the intention of the authors to carry out a user experience evaluation using a prototype serious game in a clinical population.

(JMIR Serious Games 2019;7(2):e11909) doi:10.2196/11909

KEYWORDS

PTSD; mobile applications; neuronal plasticity; cognitive behavioral therapy

Introduction

Background

In the absence of UK estimates, lifetime prevalence of posttraumatic stress disorder (PTSD) in the United States has been estimated to be between 6.8% and 7.8% [1]. This disorder is characterized by intrusive memories of traumatic events, nightmares, and avoidance of event-related stimuli [2]. In the United Kingdom, trauma-focused cognitive-behavioral therapy (TF-CBT) is the first-line treatment for PTSD [3]. TF-CBT refers to a range of evidence-based psychotherapeutic techniques for the treatment of psychological trauma. Despite a strong evidence base and wide implementation of TF-CBT, non-response and attrition rates vary widely, in some circumstances exceeding 50% [4,5]. Contributory factors that reduce optimal response to therapy in PTSD are varied, such as many possible social and behavioral factors [4]. One possible contributory variable is neural deficit associated with PTSD. Functional imaging studies suggest that reduced frontomedial neural network connectivity (eg, reduced prefrontal modulation of the amygdala) and volumetric abnormality of medial limbic structures are associated with PTSD psychopathology [6-8].

Neural Correlates of Posttraumatic Stress Disorder

According to the theoretical frameworks underpinning TF-CBT, frontomedial neural connectivity is thought to play a critical role in regulating computational processes that are integral to processing trauma memories. These processes include pattern identification, separation, and completion [9], which allow for complete retrieval and successful discrimination between contextually similar episodic or event memory formations based on familiar stimuli. Difficulty in completing these processes is a characteristic of PTSD. For example, someone who experiences posttraumatic symptoms in relation to the trauma of surviving a house fire, may experience involuntary recall of traumatic memory in response to the sight and smell of a bonfire.

There is also evidence of intrinsic medial temporal lobe (MTL) connectivity contributing to the successful processing of fear-related memory [10] and the formation of egocentric episodic memory representations [11]. Reduced neural connectivity in the MTL, especially in relation to the strong efferent connections between the retrosplenial cortex and the hippocampus, may have negative clinical implications for PTSD patients engaging in TF-CBT. This is because a core component of TF-CBT, known as *reliving*, is a form of in vitro exposure that involves the guided retrieval of episodic memory of traumatic incidents from an egocentric viewpoint in vivid detail.

Objective

Several researchers have found functional and structural plastic changes in neural circuits following the prolonged use of commercial video games and have queried the potential for therapeutic application [12-14]. Neuroimaging and behavioral data suggest that frontomedial circuitry is implicated in generating short-term memory representations related to way-finding and memory-based decision-making tasks [15,16], similar to the use of salient landmarks to aid navigation of novel three-dimensional (3D) environments [17]. In addition, mechanics such as switching between a first- or third-person perspective and an aerial map perspective of a virtual environment have been associated with recruitment of frontomedial circuitry [12]. On the basis of these data, it appears possible that a specifically designed video game (serious game) could encourage plastic changes in frontomedial neural circuitry by presenting the player with tasks known to recruit this neural network. For example, a video game could present a player with a two-dimensional aerial map representation of a novel 3D environment, inside which several objects were placed. The player could then be asked to memorize the location of each object, choose an order to collect the objects, then navigate the environment, and collect each object in the order they have chosen, aided by salient environmental landmarks.

This study aimed to find out the following:

- If a plasticity-focused serious game intervention designed to aid response to TF-CBT in PTSD patients would prove an acceptable concept to service users and providers?
- What would be the user requirements for such an intervention to be feasible and accessible?

Methods

The authors conducted a focus group (n=3) and 2 semistructured interviews (n=2) with service users and, in addition, conducted a focus group with psychological trauma service clinicians (n=4).

Participants

The recruited number of eligible participants was 9. In total, 5 participants were service users and 4 were trauma service clinicians. Among them, 1 service user participant was a female, and the remaining 4 were males. Mean age for service user participants was 59.8 years with the age range between 53 and 68 years. The duration of PTSD symptoms reported by service user participants ranged from 3 to 30 years. A total of 3 participants had experienced combat-related trauma. The nature of trauma experienced by the other service users was unknown. The clinical roles represented by the trauma service clinicians (n=4) were 1 trainee clinical psychologist, 1 assistant psychologist, 1 specialist clinical psychologist, and 1 consultant clinical psychologist. Principal inclusion and exclusion criteria are presented in Textbox 1.

Textbox 1. Principal inclusion and exclusion criteria.

- Service users
  - Inclusion criteria: aged 18 years and above; previous or current diagnosis of posttraumatic stress disorder (PTSD); in frequent and regular contact with service clinicians for treatment or other services, eg, mentoring
  - Exclusion criteria: aged under 18 years; inability to provide informed consent to participate
- Clinicians
  - Inclusion criteria: aged 18 years and above; currently working clinically with patients with PTSD
  - Exclusion criteria: not working directly with patients with PTSD; unqualified or trainee clinicians without ongoing clinical supervision

Textbox 2. Topic guide: participants and domains of inquiry.

- Service users
  - Current mobile phone capabilities
  - Coping strategies employed by service users (and those which involve mobile phone apps or Web-based resources)
  - Acceptability of the proposed intervention (including concerns)
  - Views on game presentation (in terms of graphics and audio)
- Clinicians
  - Acceptability of the proposed intervention (including concerns)
  - Views on game presentation (in terms of graphics and audio)

Materials

A topic guide was developed by the authors and used for both the focus groups and interviews. Open-ended questions with prompts addressed a total of 5 broad domains of inquiry (as summarized in Textbox 2). All topics were explored in each interview and focus group. Interviews lasted between 30 and 60 min, and focus groups lasted between 90 and 120 min. Demographic data, including age and gender, were requested from service user participants only. We sought permission from all participants to make live written notes and audio-record interviews and focus groups on digital voice recorders placed on a table, around which participants and researchers sat. All audio and written data were transcribed verbatim on a later date.

Procedure

To identify and engage members of the target population for recruitment into the study, the authors approached several organizations, including third sector organizations and National Health Services. A branch of a national charity offering mental health mentoring and practical support to military veterans in South Wales, responded promptly and positively to our queries. One-to-one interviews were carried out at the charity's premises during April 2017. We decided not to include the name and location of this service in the interest of the confidentiality and anonymity of study participants. The psychological trauma service at Springfield University Hospital in Tooting, London, also responded positively and promptly to our enquiries. Focus groups involving patients and clinical staff were carried out here in June 2017.

Data Analysis

Data were thematically analyzed, summarized, and described in relation to our domains of inquiry. As the interviews were relatively unstructured and we sought to assess acceptability rather than develop a theory of theoretical framework, we attempted to calculate interrater reliability.

Results

Current Service User Mobile Phone Capabilities

Of the 5 service user participants, 4 owned a mobile phone and 1 owned an older generation mobile phone. Of the 4 participants who owned a mobile phone, 3 owned a mobile phone running Google's Android operating system and the other used a phone running Apple's iOS. Participants' mobile phones were capable of running software apps, and all reported social media apps that were their favored and most frequently used apps. These included Facebook, Facebook Messenger, and WhatsApp.

Existing Coping Strategies Reported by Service Users

All participating service users reported reliance on particular lifestyle-related strategies to cope with PTSD symptoms. The majority of participants reported social support (through either friends or family or organized support groups) and engagement in outdoor activities, including cycling and dog walking. All but one participant reported using mobile apps in seeking support from others (eg, Facebook, WhatsApp, short message service text messaging, phone).

All participating service users reported that PTSD had adversely affected their memory. Participants gave examples of impaired episodic and prospective memory capacity, such as frequent examples of the *doorway effect* and forgetting seemingly meaningful upcoming or past events, particularly when stressed. Out of the 5 service users, 3 participants did not use any memory-specific coping strategies, whereas 1 participant reported using mobile phone to create calendar reminders, and 1 reported writing things down using a pen and paper. Walking and cycling were reported to be helpful activities by 2 participants, and 1 reported using Google Maps for planning cycling routes. All but 1 had previous TF-CBT; all reported current medication with selective serotonin reuptake inhibitors.

No participants had used Web-based resources to help them cope with PTSD symptoms. Only 1 of 5 participants reported having used an app called PTSD Coach [18] released by the United States Department of Veterans Affairs. The app focuses on education around PTSD and symptom tracking and is marketed as a therapeutic tool. They described the app as unhelpful and were no longer using it. No participant reported actively using general health or well-being–related apps. Usage of relaxation and meditation apps were reported by 2 participants (these were the freely available *Stop, Breathe and Think* and *Smiling Mind* Android apps) [19,20], which included scripted meditation and relaxation exercises. Both participants described these as unhelpful, with 1 participant describing the sensation of being *out of control* when using the apps, as they were anxiety inducing.

Service Users' Reported Acceptability of the Proposed Serious Game

All participants described themselves as being willing to try the proposed serious game intervention. Only 1 participant was less enthusiastic about using the app along with therapy than before therapy, and 1 was concerned that using the app would interfere with therapy rather than enhance it; however, these concerns could be alleviated if assurance of the game's efficacy was provided by a clinician. All participants stated that they would be more confident about using the app under the guidance of a clinician.

Of the 5 participants, 3 stated that they would be unlikely to use the app at times when they were experiencing acute symptoms of PTSD, for example, experiencing a flashback or symptoms of panic. Only 1 participant described long periods of inactivity alluding to depressive symptoms as potential barrier to using the app. All agreed that the app would have to be easy to use and intuitive in its design. All participants expressed concern that if the game were too difficult, they may become frustrated and cease using it relatively quickly. Should this not be the case, 2 participants stated that they would be willing to use the app for 30 min every day over a prolonged period (defined by the interviewer as between 3 and 6 weeks). The remaining 3 participants stated they would be willing to use the app for 30 min every other day over the same period. All participants were enthusiastic about the prospect of patients using the serious game while on a waiting list. They described positive implications for self-efficacy:

> *...you're not just waiting for someone to help you then, you are doing something [to help] yourself.*

All participants were positively inquisitive about the concept behind the proposed serious game, especially the fact that the game would not include a psychotherapeutic component to address PTSD or PTSD-related symptoms directly. No participant reported any concerns or negative attitudes toward the concept underpinning the proposed serious game when prompted, for example:

> *What do you think of the serious game concept?*
>
> *Do you think this could work for you?*

Service Users' Views on the Proposed Serious Game's Graphics and Audio Components

In terms of graphical and audio design features that would be beneficial to the user experience, all participants favored an expansive outdoor environment. Water, in the form of rivers and lakes, including the sound of naturally running water was described as desirable by 4 participants. However, beaches were described as reminiscent of combat trauma and therefore especially undesirable by 2 of the 4 participants. Desert landscapes were also described as undesirable. Woods and greenery were described as desirable by 4 participants, and 1 participant described the ideal aesthetic to be that of a garden. The need for the player to be able to choose different seasons for the environment before the play was expressed by 3 participants. No participant desired the inclusion of human characters in the environment; however, 3 enthusiastically favored the inclusion of wildlife such as dogs, birds, and horses.

At the time of the focus groups and interviews, the researcher would describe the need for novel landmarks to be located in the environment and ask the participants how they would like these to be represented. In response to this query, mountains and trees were described as ideal landmarks by all participants. Man-made structures were described by 3 participants, with Buddhist temple or similar architecture being the favored choice.

Clinicians' Reported Acceptability of the Proposed Serious Game

As with service user participants, clinicians were positively inquisitive about the concept behind the proposed serious game. Clinicians were more likely to inquire about the theoretical basis for the intervention. No clinician reported any concerns about potential adverse effects; however, all participants favored clinician-guided use of the game as opposed to independent use. It was the prevailing view that a significant proportion of patients would require coaching in using the game with adequate frequency.

Clinicians' Views on the Proposed Serious Game's Graphics and Audio Components

When discussing the sound and graphics content of the game, all participants agreed that the game must avoid sound and graphic content likely to trigger symptoms of PTSD. All agreed that the more realistic the environment was, the more difficult this task became, and so a *cartoon-like* or abstract appearance for the environment was favored. It was accepted that creating an environment that guaranteed not to trigger symptoms of PTSD in any player would be infeasible. However, it was accepted that creating an environment that was unlikely to trigger PTSD symptoms for the majority of users was feasible, especially if the environment was customizable and the game was carefully prescribed.

Clinicians stated that the game should match the patient's abilities:

> *...if the game is too boring, the patient would disengage, weakening the effect of the experimental manipulation.*

Service users, on the other hand, were more concerned with the amount of concentration required to sustain while playing the game; if they had to concentrate too hard, they could get frustrated and give up. This balance of skill and difficulty is referred to as a component of *flow* theory and is frequently referenced when designing games for educational and clinical purposes [21].

Clinicians raised the issue of increasing the numbers of asylum seekers seeking help for PTSD in the United Kingdom in recent years. As many of these service users may have difficulty understanding English, the game interface must be intuitive and include very little text guidance. Translating the game into many different languages would present a less feasible option, given the available funding and resources. In addition, in the clinician's experiences, many patients who had arrived in the country seeking asylum had come from Middle Eastern and North African countries and had experienced trauma not only in the countries from which they were escaping but also during their perilous journeys to the United Kingdom. For this reason, graphics of beaches, large expanses of open water, boats, lorries, and desert landscapes were deemed undesirable.

Discussion

Principal Findings

We captured qualitative data regarding the acceptability of a plasticity-focused serious game to aid response to TF-CBT for PTSD from a small sample of service users and clinicians. These data suggest that the concept of such an intervention is acceptable to both groups and can be made accessible to the target population who mostly have access to capable hardware. Care must be taken in terms of graphical and audio content to ensure that the game does not elicit trauma symptoms in service users and is accessible and easy to use. This represents a significant design challenge given the highly varied clinical population in question. It was the view of the service users and clinicians that the game usage should be guided by a therapist. The issue of negative affect influencing motivation and poor prospective memory in PTSD patients reinforced the need for therapist involvement. It was also accepted that the game would not be suitable for all patients, and so the clinicians would have to use their knowledge and expertise to appropriately prescribe usage of the game.

Limitations

This study was limited by a small and opportunistic sample, most notably missing asylum-seeking representatives. Participants had received a diagnosis of PTSD by specialist trauma clinicians. Details of individual's diagnosis, including the nature of the trauma or traumas, or the symptom severity at the time of participation, were not available to the researchers. In addition, we did not collect data related to spiritual or religious beliefs, which could have helped put in to context the preference for Buddhist style structures in the virtual environment.

Future Steps

We propose to complete user-experience testing with service users and clinicians using a prototype video game running on a medium-specification Android device. We will measure readiness to use a digital intervention such as Hippocampal and Prefrontal Plasticity Inducement Application (HAPPIA), using a previously validated method of assessment such as the eHealth Readiness Scale [22], and include a user satisfaction questionnaire to supplement our qualitative data collection. We will also formally measure aspects of participant's individual pathology using validated tools. For example, we will measure engagement in existing coping strategies for trauma symptoms using the Trauma Coping Self-Efficacy scale [23]; the Life Events Checklist will be used to assess the nature of experienced trauma events [24]; and the Posttraumatic Stress Disorder Checklist for the Diagnostic and Statistical Manual of Mental Disorders, fifth edition will be used to measure symptom severity [25]. Data from this testing will be used to refine the design of the software and further inform the choice of hardware used to deliver the intervention before clinical evaluation. Screenshots from the in-development prototype informed by the qualitative data reported here are presented below. The prototype dubbed "HAPPIA" has begun development using the Unity software engine developed by Unity Technologies and is optimized to run on medium-spec Android devices including mobile phones and tablet personal computers.

Following further refinement and development of the HAPPIA app by way of user-experience testing, we will seek to evaluate HAPPIA as a clinical intervention by carrying out a randomized controlled trial. Patients awaiting a course of TF-CBT will be randomly assigned to HAPPIA plus treatment as usual (TAU) or TAU alone. Symptom severity at the outset of treatment, at cessation of treatment, and at follow-up will be measured using validated psychometric measures and compared among groups. Attrition rates and changes in psychotropic medication (eg, anxiolytics) dosage will also be compared among groups. We will capture demographic data, including age and gender, for clinical participants. HAPPIA will record game-related data, including time spent playing the game, time taken to complete tasks, and efficiency of task completion for within-group analysis.

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Conflicts of Interest

None declared.

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Abbreviations

3D: three-dimensional

HAPPIA: Hippocampal and Prefrontal Plasticity Inducement Application
MTL: medial temporal lobe
PTSD: posttraumatic stress disorder
TF-CBT: trauma-focused cognitive-behavioral therapy

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Original Paper

Development of CliniPup, a Serious Game Aimed at Reducing Perioperative Anxiety and Pain in Children: Mixed Methods Study

Sarah Verschueren[1], PhD; June van Aalst[2], BSc, MSc; Anne-Marie Bangels[3], BSc; Jaan Toelen[3], MD, PhD; Karel Allegaert[3,4], MD, PhD; Connor Buffel[5], BSc, MBT; Geert Vander Stichele[1], MSc, PharmD

[1]MindBytes BVBA, Merksplas, Belgium

[2]Division of Nuclear Medicine and Molecular Imaging, Department of Imaging and Pathology, KU Leuven, Leuven, Belgium

[3]Department of Development and Regeneration, KU Leuven, Leuven, Belgium

[4]Division of Neonatology, Department of Pediatrics, Erasmus MC-Sophia Children's Hospital, Rotterdam, Netherlands

[5]MindLab Interactive AI Inc, Edmonton, AB, Canada

Corresponding Author:
Sarah Verschueren, PhD
MindBytes BVBA
Schoondreef 7
Merksplas,
Belgium
Phone: 32 476753516
Email: sarah.verschueren@hotmail.com

Abstract

Background: An increasing number of children undergo ambulatory surgery each year, and a significant proportion experience substantial preoperative anxiety and postoperative pain. The management of perioperative anxiety and pain remains challenging in children and is inadequate, which negatively impacts the physical, psychosocial, and economic outcomes. Existing nonpharmacological interventions are costly, time consuming, vary in availability, and lack benefits. Therefore, there is a need for an evidence-based, accessible, nonpharmacological intervention as an adjunct to existing pharmacological alternatives to reduce perioperative anxiety and pain in children undergoing ambulatory surgery. Technology-enabled interventions have been proposed as a method to address the unmet need in this setting. In particular, serious games hold a unique potential to change health beliefs and behaviors in children.

Objective: The objective of this research was to describe the rationale, scientific evidence, design aspects, and features of CliniPup, a serious game aimed at reducing perioperative anxiety and pain in children undergoing ambulatory surgery.

Methods: The SERES Framework for serious game development was used to create the serious game, CliniPup. In particular, we used a mixed methods approach that consisted of a structured literature review supplemented with ethnographic research, such as expert interviews and a time-motion exercise. The resulting scientific evidence base was leveraged to ensure that the resulting serious game was relevant, realistic, and theory driven. A participatory design approach was applied, wherein clinical experts qualitatively reviewed several versions of the serious game, and an iterative creative process was used to integrate the applicable feedback.

Results: CliniPup, a serious game, was developed to incorporate a scientific evidence base from a structured literature review, realistic content collected during ethnographic research such as expert interviews, explicit pedagogical objectives from scientific literature, and game mechanics and user interface design that address key aspects of the evidence.

Conclusions: This report details the systematic development of CliniPup, a serious game aimed at reducing perioperative anxiety and pain in children undergoing ambulatory surgery. Clinical experts validated CliniPup's underlying scientific evidence base and design foundations, suggesting that it was well designed for preliminary evaluation in the target population. An evaluation plan is proposed and briefly described.

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KEYWORDS

serious games for health; behavior change; perioperative pain; perioperative anxiety; pediatric; ambulatory surgery

Introduction

Background

According to the latest data, over 25,000 ambulatory surgical procedures are performed on children aged 6-10 years in Belgium each year [1]. Moreover, ambulatory surgical interventions in children are increasing in developed nations such as the United States and United Kingdom [2-3]. Ambulatory surgical procedures are associated with significant levels of perioperative pain and anxiety in children, with 40%-60% experiencing high levels of anxiety on the day of surgery and >30% experiencing moderate-to-severe postoperative pain [4-6]. Inadequate management of perioperative pain and anxiety results in negative short- and long-term physical and psychosocial outcomes such as delirium, sleep disturbances [7-10], delayed wound healing, postoperative immunosuppression, increased susceptibility to infection, and distrust of health care practitioners (HCPs), which is a risk factor for future health care avoidance [5,11-13]. As a bidirectional relationship between pain and anxiety has clearly been established, perioperative anxiety can influence a child's pain experience and vice versa [14-16]. Inadequate management of perioperative pain and anxiety also results in negative economic outcomes such as HCP burden, child absenteeism, parent absenteeism, inpatient admission, and increased analgesic and anxiolytic consumption [5,11-13,17]. In addition, preoperative anxiety in both children and their parents affects children's experience of perioperative pain [7-9,16].

Management of perioperative pain and anxiety is particularly challenging in children, because they experience pain and anxiety differently from adults, have limited skills to communicate pain and anxiety, and often have a limited understanding of the surgery purpose and process [8,18-20]. Furthermore, the use of pharmacological interventions to alleviate preoperative anxiety, such as anxiolytics, is associated with adverse effects (eg, paradoxical reactions) and, in certain cases, delay discharge [11,12,21,22]. Adverse effects also pose a problem for pharmacological treatments targeted at perioperative pain and as such, HCPs and parents may inadequately manage postoperative pain, leading to undertreatment [23-30].

Although there is minimal standardization across surgical centers, nonpharmacological interventions are also used to address perioperative anxiety and pain in children. These interventions vary in their objectives, with some offering distraction or information only and others focusing on behavior change (coping strategies, communication skills, etc). Nonetheless, the majority remain costly, time-consuming, and surgical-center specific [8,9,19,31,32]. In contrast, other interventions such as distractions may also be effective in reducing preoperative anxiety [9,31,33]. Although these options are less constrained by cost and time compared to the alternatives, they transiently reduce anxiety [31], offering little in the way of information provision, modeling, and coping skills—the three most effective strategies to prepare children for surgery [8]. This is particularly relevant in children aged >4 years who prefer to maintain control [9,19].

One potential nonpharmacological intervention that has shown efficacy in children is serious games. These digital tools can not only be inexpensively and widely deployed, but also offer the potential to transfer knowledge and educate users in an interactive and engaging manner, which can lead to behavior change [34-36]. Aligned with these features, serious games have proven to be particularly useful when targeted toward children in health care settings [37-39]. In fact, there are a number of studies investigating digital interventions aimed at reducing child perioperative pain and anxiety [33,40-42]. However, most of these options rely on pure distraction. The approach explored in this research focuses on achieving behavior change by educating children in a fun and engaging manner through experiential learning. The use of experiential learning is aligned with the theory of Cognitive Neuroeconomics, which states that individuals revert to experiential thinking, as opposed to rationale thinking, when under stress [43]. In the context of perioperative pain and anxiety, this suggests that children need *information* on various aspects of surgery and behavioral skills (communication and coping techniques) and to *experience* their surgical journeys (purpose, process, etc) in a safe and playful environment [8,19]. This thinking is also aligned with the optimal strategies to prepare children for surgery (information, modeling, and coping skills), which has been described by Fortier et al [42] and is consistent with various psychological and behavior change models [43-46].

Objective

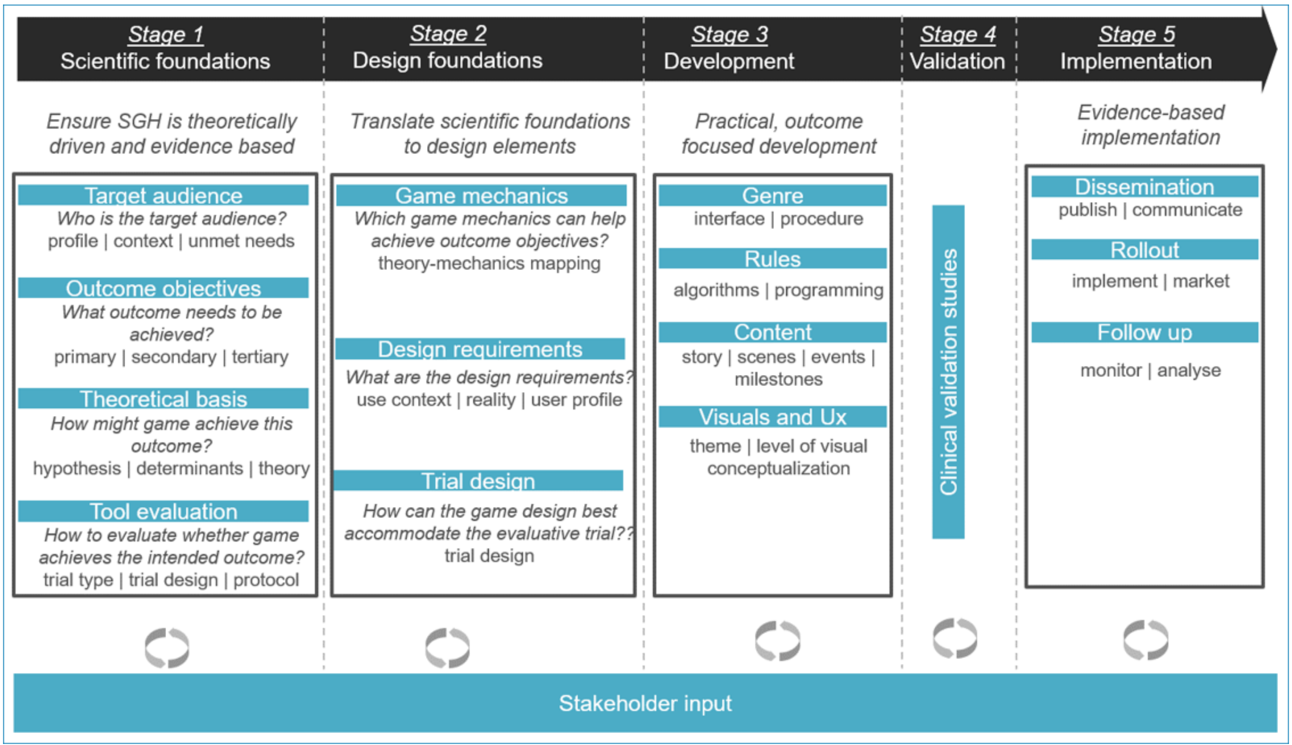
The objective of this research was to develop an evidence-based serious game aimed at reducing perioperative anxiety and pain in children undergoing ambulatory surgery. The purpose of this paper was to describe the rationale, scientific evidence, and subsequent translation of that framework into design and game mechanic features that comprise the serious game CliniPup.

Methods

Overview

To create an evidence-based game that is purposefully designed to address relevant challenges faced by the target end user and change behavior, CliniPup was developed using the SERES Framework [47]. The SERES Framework, developed by the authors SV, CB, and GVS, was applied to ensure that the serious game was theory driven and evidence based [47]. The framework covers all aspects of the development process (scientific, technological, and design) and is transparently described in sufficient detail to allow developers to implement it in a wide variety of projects, irrespective of discipline, health care segment, or focus. It consists of five distinct stages (Figure 1). Each stage has a specific focus and is informed by various stakeholders. Several iterations of development may occur within a given stage, progressively refining the serious game based on testing and feedback from relevant stakeholders [47]. The application of this method in the context of pediatric perioperative anxiety and pain is described in the sections below, with a focus on Stages 1, 2, and 3, which represent the underlying Scientific Foundations, Design Foundations, and Development, respectively.

Figure 1. SERES Framework used to develop CliniPup. Adapted from Verschueren et al [47].



Scientific Foundations

Target Audience

Sound Scientific Foundations for CliniPup were established at the earliest stage of development to ensure that the game was relevant, theoretically driven, and evidence based, in line with the governing research methodologies. This stage assessed, based on objective criteria, whether there was a relevant unmet medical need for a clearly defined target audience that can be addressed with a serious game. In line with this aim, an exploratory review of the research literature on perioperative anxiety and pain was performed. To this end, the PubMed database was search electronically from March to April 2015 with a search strategy (terms used in duplicate: pain, anxiety, surgery, perioperative, children, and pediatric). The following criteria were applied for inclusion: English language and review. Similarly, the following criteria were applied for exclusion: published before 2000 and nonpediatric population.

Outcome Objectives

This stage assessed what the objectives of a serious game should be in the context of the target audience defined in the first step. Evidence collected in the exploratory literature search was reviewed again with the aim of defining the outcome objectives.

Theoretical Basis

Formulating a hypothesis of how a serious game might achieve the intended outcome objectives is a vital step toward purposeful design and the evaluation and validation of its causal effect on the outcome [47]. In particular, modifiable barriers and drivers (outcome determinants) contributing to pain, anxiety, and control in children were collected from the scientific literature. To this end, a critical review of the scientific literature was performed. From September to October 2015, the PubMed database was searched electronically with the following search strategy: pain OR children OR preoperative, postoperative OR anxiety OR induction OR perioperative OR education OR pharmacological treatment OR non-pharmacological treatment OR determinants. The following criteria were applied for inclusion: English language, review, case study, retrospective study, and clinical trial. The criteria for exclusion were published before 2000, nonpediatric population, and pharmacological intervention only.

Barriers and drivers (determinants) were extracted directly from the literature and classified into categories, thereby arriving at a manageable amount of key factors. The relative importance of each determinant was also defined based on qualitative descriptions in the selected articles. Moreover, various experts in the field such as nurses, pediatricians, and surgeons were consulted to evaluate the resulting determinant categories.

Consistent with the SERES Framework Methodology, learning objectives were defined for each determinant and subsequently mapped within a theoretical framework. The Information-Motivation-Behavioral skills (IMB) model of behavior change was selected as the theoretical framework because it has been used in the design of health promotion interventions and was aligned with educational strategies to prepare children for surgery in the literature [8,44]. These learning objectives, in turn, guided the Design Foundations.

It also became evident that there were a substantial number of clinical practice documents available, which were not considered primary research. Therefore, the secondary literature on educational programs for children in the perioperative setting was also reviewed. These findings played an important role in informing the learning objectives and various game design aspects, which are described in the Results section.

Tool Evaluation

Both the literature collected via the exploratory search and the critical review were analyzed to understand how to validate a serious game in the context of a nonpharmacological intervention aimed at addressing perioperative anxiety and pain in children. The findings were integrated into the game design process and the subsequent clinical evaluation.

Design Foundations

To ensure CliniPup could achieve the intended outcomes, the Scientific Foundations established in the first phase guided the choice of game mechanics, design, and technological features. Therefore, the theoretical basis was translated into relevant, implementable game design elements.

Game Mechanics

Game mechanics (GMs) are rules or methods that define the interactions and flow of a game session. They describe interactions, game conditions, and triggers in an abstract manner. In 2015, Arnab proposed a model for translating learning objectives into learning mechanics (LM) and mapping these to relevant GMs [48]. This so-called LM-GM model guides developers in the development of more effective, pedagogy-driven serious games, as it ensures that game mechanics are selected based on their ability to contribute toward the intended outcomes [48]. The LM-GM model was utilized to map GMs to the learning objectives identified in the Scientific Foundations stage. For example, one such learning objective was to recall the sequence of events for the upcoming procedure (knowing what to expect and do). This involves Blooms' Ordered Thinking Skills "understanding" and "retention." Based on the LM-GM model, several LMs address these thinking skills: "exploration," "repetition," and "planning" [48]. Each of these LMs was, in turn, mapped to one or more GMs such as "story," "cascading information," and "strategy/planning" [48]. As such, the scientific foundations established in Stage 1 were explicitly and systematically translated into the game construct. The implementation of selected GMs in the resulting serious game was then documented to retrospectively assess the translation to the game development stage and ensure that the selected GMs were indeed applied.

Design Requirements

Based on findings from the biomedical literature and through interaction with key stakeholders (nurses, pediatricians, parents, etc), a time-motion exercise was carried out to map anxiety and pain throughout a child's (and their parents) surgical journey. Additionally, when and where (which setting) each of the outcome determinants was most relevant was identified. In turn, this information helped to define various aspects of the serious game such as which characters (stakeholders) should be included, the relevant settings to incorporate, key time points to address, and the most applicable visuals and content elements.

Game Development and Description

The game development stage represented the creative translation of all evidence collected in the preceding stages toward a fun and engaging educational tool. The learning objectives, GMs, and design requirements were, in particular, used as a framework to ensure the resulting serious game was evidence based. An iterative, stepwise process was carried out, in which a storyboard was first created followed by the development of visuals, graphics, and a user interface. Utilizing a participatory design approach, feedback of clinicians was sought to refine the serious game. The visuals and user interface were generated using Articulate Storyline, a computer program typically used in the development of electronic learning.

Results

Scientific Foundations

Target Audience

Based on review of the literature, the target audience was defined as children aged 6-10 years with a high unmet medical need at the individual and population level. Although other age segments also showed unmet needs, children aged 6-10 years were selected due to the substantial physical, psychological, social, and economic burdens associated with inadequate preparation and management [5,8,19,28,29]. Moreover, management for children in this segment was considered especially challenging because of several unique characteristics: need for support and information, need for control, capacity to understand age-appropriate information, lack of communication and coping skills, and limited understanding of the surgical purpose and journey [8,19,30,41,49]. In addition, this segment undergoes a robust amount of ambulatory procedures each year [1,3].

Due to the relationship between parental factors (knowledge, skills, behavior, etc) and children's pain and anxiety, parents are also an important target audience for a nonpharmacological intervention [8,9,16,28]. Therefore, parental unmet needs must be addressed simultaneously. Parental needs are mainly related to coping and communication skills, support, and information on the surgery process and journey [8,19,25,29].

Outcome Objectives

There is a particular need to educate children and their parents about the concepts of pain and anxiety, allow them to explore the surgical pathway, and change their behavior with respect to communication and coping [8,19]. These needs are intended to indirectly, or directly, address the overarching goals, which are to reduce child anxiety and pain in the perioperative setting.

Theoretical Basis

The literature search, described in the Methods, resulted in the selection of nine articles for inclusion in the study [8,17,18,25,29,30,49-51].

After review, it was clear that pain and anxiety have sensory, emotional, cognitive, and behavioral components that are interrelated with environmental, developmental, sociocultural, and contextual factors [8,12,52]. A number of determinants of pain and anxiety were considered fixed (eg, risk factors) or nonmodifiable and could not be addressed with an intervention (eg, child demographics, parent demographics, and type of procedure) [17,30]. Seven key modifiable determinants were identified: medical fears, current state, sense of control, ability to communicate, understanding (information/knowledge), focus on pain, and parental fears. These seven determinants were generated through categorization of approximately 100 relevant underlying parameters, which were directly defined in the literature. The determinants were also closely aligned with clinical experience suggesting that the following psychological factors are known to influence pain and therefore should be addressed by nonpharmacological interventions: vigilance to pain, avoidance, anger, involvement of the patient, making sense of the pain, and consistency [53]. In turn, the learning objectives were defined for each determinant, and a theoretical mechanism was defined as information, motivation, or behavioral skills, consistent with the IMB model (Multimedia Appendix 1).

As the focus of the development was on a serious game directed at children, it was determined to be infeasible (and impractical) to address the parental learning objectives alongside the child's learning objectives in a single serious game. However, the parental learning objectives remain critical factors that should be addressed through a complementary or supplementary mechanism or medium.

The learning objectives were further categorized together to yield 11 identified objectives (Table 1).

Tool Evaluation

Common approaches in the field to evaluate interventions leveraged structured clinical trials, and therefore, the researchers determined that the optimal approach to evaluate CliniPup was with a randomized controlled clinical trial [35,37,38]. With this in mind, a positive first step is to validate CliniPup in a pilot study before considering a larger, pivotal trial. Through this process, key validated outcome measures were identified for pediatric anxiety and pain and parental anxiety. These measures were examined using the modified Yale preoperative anxiety scale, the Wong-Baker Faces Pain Rating Scale (WBFPRS), and the state-trait anxiety inventory [10,54,55]. In addition to the clinical measures, an evaluation of user satisfaction and experience could also be performed in a pilot trial. Data on these aspects could be collected using structured questionnaires and Likert scales.

Design Foundations

Screenshots of CliniPup are shown in Figures 2-15. LMs and GMs were selected based on Bloom's ordered thinking skills that were aligned with the learning objectives (Multimedia Appendix 1), consistent with the LM-GM model (Table 1) [48]. Further, the implementation of the GMs at the development stage is also presented in Table 1 for complete transparency.

Design Requirements

Based on the biomedical literature review and interviews with clinicians, it was established that the characters portrayed in the serious game needed to be realistic, yet age-appropriate, especially when visualizing medical professionals [8,41]. Parents should be visualized as kind, gentle, and comforting [8,19,44]. In addition, the literature indicated that the game's protagonist should be authoritative; likable; relatable; and neutral in gender, age, and ethnicity [8]. Aligned with these points, the use of a nonhuman protagonist, such as an animal, was considered. Further research indicated that animals may offer a positive, comforting role model for children, and therefore, a dog, called CliniPup, was developed to represent the serious game's protagonist [56,57].

The design requirements for the serious game's settings were informed mainly by the ethnographic research performed (eg, time-motion exercise and interaction with medical stakeholders). This research suggested that the settings should be linked to the surgical journey and therefore cover the following environments: at home before the surgery, at the hospital before the surgery, at the hospital in the operating room, at the hospital after the surgery, and at home after the surgery [8,19]. The relevance of each of the seven determinants to the different settings was mapped using the time-motion exercise.

Due to the unique pedagogical requirements (eg, short attention span and limited language capabilities) of children aged 6-10 years, the serious game needed to be highly engaging, interesting, and fun [19]. In particular, age-appropriate visuals and language were recommended for educational tools used in health care settings targeted at children in order to enhance engagement [8,17,19]. This suggested that the use of dynamic animations, sounds, voice-overs, and limited text would be optimal. These choices are aligned with the Gestalt theory, which recommends that designers should limit cognitive efforts for optimal communication, particularly in health care settings [58,59]. Additionally, the use of multimedia techniques increases the likelihood of addressing heterogeneous learning styles, facilitating education in a diverse target audience [8,59,60].

Tool Evaluation: Implication on Design

With the pilot study design, we expected children to play the serious game CliniPup in their home setting and believed that all outcome data would be collected outside of the game itself. Therefore, minimal design requirements were necessary to accommodate the trial. At-home play was facilitated by designing the serious game to be accessible online and functional in both mobile and desktop environments. In addition, the serious game was linked to a database to allow for the collection and storage of demographic and user interaction data (eg, number of times played).

Game Development and Description

CliniPup was developed based on evidence generated from the Scientific Foundations and Design Foundations. A general narrative that explored the ambulatory surgical journey was presented, and a user interface was created to realize the narrative, as described in the Design Foundations (Figures 3-7). The use of this narrative was intended to directly address learning objectives 4, 5, and 6 and to indirectly address all other learning objectives listed in Table 1. The user interface was 2D and cartoon-like, aligned with target audience expectations. The protagonist, CliniPup, was visualized as confident, fun, and authoritative (Figure 2).

Table 1. Learning objectives, Bloom's ordered thinking skills, learning mechanics, game mechanics, and game implementation for the serious game CliniPup.

#	Learning objective	Thinking skill	Learning mechanic	Game mechanic	Game implementation
1	Describe hospital environment, identify types of medical staff involved and their role	Retention, Understanding, Applying	Observation, Exploration, Question and answer	Tutorial, Question and answer, Feedback	• Hospital environment and medical staff described during narrative (Figure 5) • Mini-game exploring objects and people in the operating room (Figures 9-11)
2	Explain relevant age-appropriate medical terms	Retention, Understanding, Applying	Tutorial, Observation, Identification, Question and answer	Tutorial, Question and answer, Feedback, Realism	• Hospital environment and medical staff described during narrative (Figure 5) • Use of age-appropriate terminology (eg, "sleep doctor"; Figure 10) • Mini-game allowing exploration of hospital environment and answering questions related to the hospital environment (Figures 9-11)
3	Distinguish facts and myths related to day surgery (eg, "may not wake up")	Understanding	Tutorial, Exploration	Tutorial, Story	• Linear sequence of events consistent with events of the day of surgery described during the narrative (Figures 3-7) • Common myths addressed directly during the narrative
4	Recall the sequence of events for the upcoming procedure	Retention, Understanding, Applying	Exploration, Repetition, Strategy/planning, Question and answer	Story, Tutorial, Question and answer, Feedback	• Linear sequence of events consistent with events of the day of surgery described during the narrative (Figures 3-7) • Mini-game about the sequence of events on the day of surgery (Figure 12)
5	Plan the at-home steps to prepare for the surgery	Understanding, Applying	Tutorial, Question and answer	Tutorial, Question and answer, Feedback	• At-home sequence (Figure 3) • Mini-game about the sequence of events at home (Figure 12) • Mini-game about control at home (Figure 14)
6	Describe how it may feel on the day of surgery (what, when, why)	Understanding, Applying, Evaluating	Tutorial, Exploring, Question and answer, Action/task	Tutorial, Question and answer, Capture/elimination, Rewards/penalties	• Linear sequence of events consistent with events of the day of surgery described during the narrative (Figures 3-7) • Anxiety monsters mini-game at various points of anxiety (Figure 8) • In-game score (Figure 15)
7	Explain what anxiety and pain are (manifestation, purpose, transient nature)	Understanding, Applying	Tutorial, Question and answer	Tutorial, Question and answer	• Age-appropriate feeling described during the narrative (butterflies, lump in throat, etc) • Choosing where anxiety is experienced somatically • Anxiety monsters are transient (not constant)
8	Recognize when they are experiencing anxiety and pain (telltale signs)	Understanding, Analyzing, Evaluating	Tutorial, Action/task	Tutorial, Feedback, Capture/elimination, Rewards/penalties	• Age-appropriate explanation of anxiety and pain during narrative • Anxiety monsters mini-game at various points of anxiety (Figure 8) • Demonstration of WBFPRS[a] (Figure 6) • In-game score (Figure 15)

#	Learning objective	Thinking skill	Learning mechanic	Game mechanic	Game implementation
9	Demonstrate confidence to discuss with parents, caregivers, or medical staff	Understanding, Applying	Tutorial, Question and answer	Question and answer	• Communication with HCPs[b] and parents reinforced as positive • Mini-game about options related to control on day of surgery (Figure 14)
10	Describe and label feelings of pain or anxiety	Understanding, Analyzing	Tutorial, Question and answer	Question and answer, Feedback	• Age-appropriate explanation of anxiety and pain • Demonstration of WBFPRS in the narrative (Figure 6) • Mini-game with WBFPRS (Figure 13)
11	Use coping skills for dealing with anxiety and pain	Understanding, Applying, Evaluating	Tutorial, Questions and answer, Assessment	Tutorial, Question and answer, Feedback, Action points	• Dealing with anxiety explored during the narrative (distraction, communicating, choosing "Clini-buddy," etc) • Mini-game about options related to control on day of surgery (Figure 14)

[a]WBFPRS: Wong-Baker Faces Pain Rating Scale.

[b]HCP: health care practitioner.

Figure 2. CliniPup introduction and visuals.

Figure 3. CliniPup narrative visuals: At home before surgery.

Figure 4. CliniPup narrative visuals: At the hospital before surgery.

Figure 5. CliniPup narrative visuals: In the operating room.

Figure 6. CliniPup narrative visuals: In the hospital after surgery.

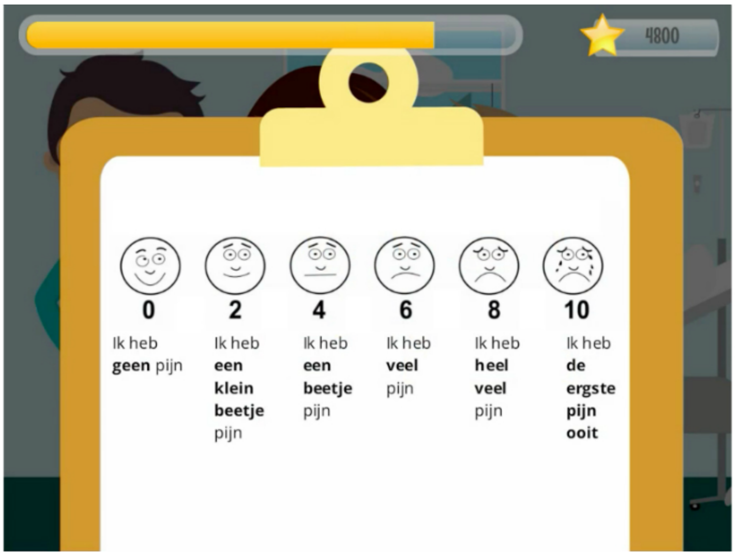


Figure 7. CliniPup narrative visuals: At home after surgery.

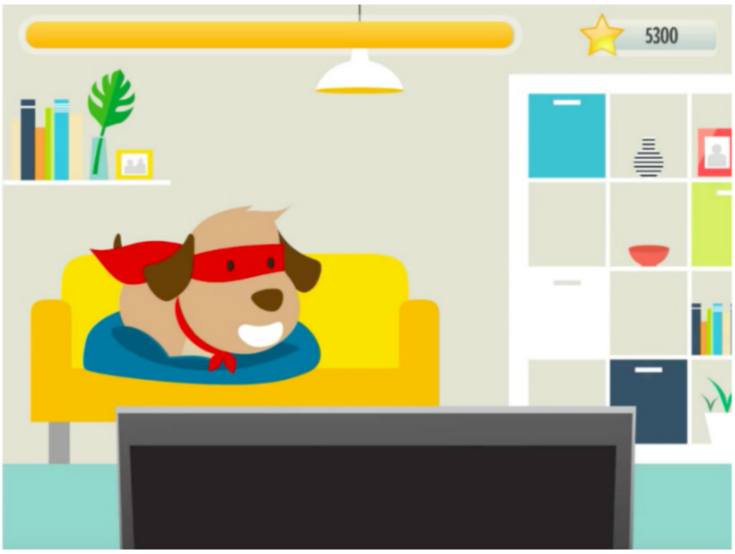


Figure 8. CliniPup anxiety monster mini-game.

Figure 9. CliniPup quizzes and challenges: Operating room and object names.

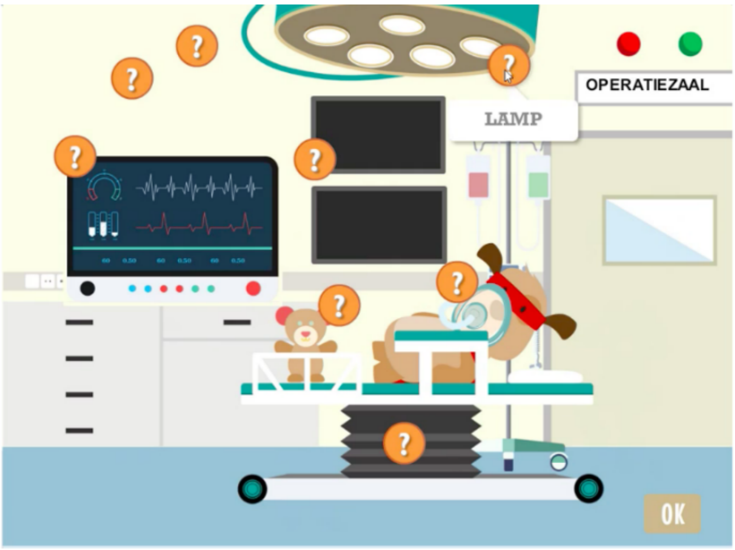


Figure 10. CliniPup quizzes and challenges: People in the operating room.

Figure 11. CliniPup quizzes and challenges: Operating room and matching.

Figure 12. CliniPup quizzes and challenges: Sequence of events throughout the day of surgery.

Figure 13. CliniPup quizzes and challenges: Wong-Baker Faces Pain Rating Scale and matching.

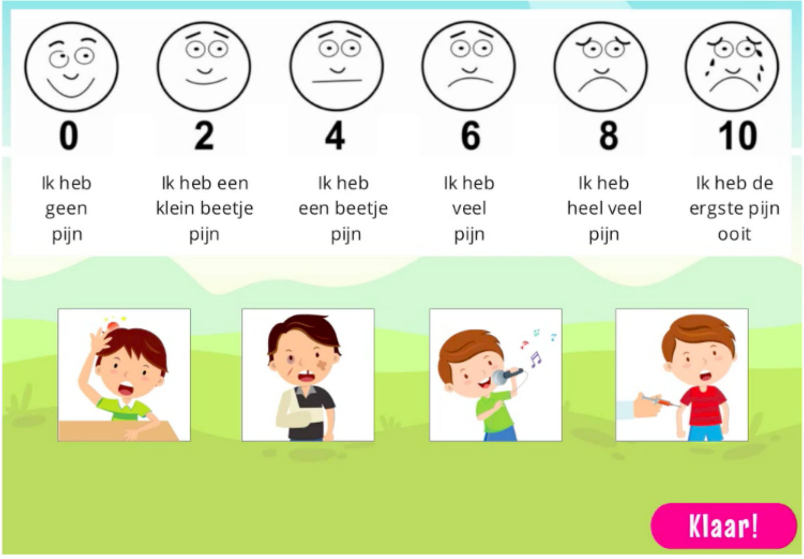


Figure 14. CliniPup quizzes and challenges: Options for exercising control throughout the day of surgery.

Figure 15. CliniPup final score screen.

Consistent with the design requirements, minimal text was presented and voice-overs and sounds were implemented throughout. In particular, the narrative followed the five key settings of the surgical journey defined in the Design Requirements (Figures 3-7). The tool was accessible online and could be played on a personal computer or tablet.

“Anxiety monsters” would appear at key moments (defined by the time-motion exercise), in which users needed to help the protagonists chase them away (by clicking on the monsters; Figure 2). The purpose of this mini-game was to achieve learning objectives 8, 9, 10, and 11 (Table 1), and it served the purpose of collecting points for the user, which represented the overarching in-game objective (Figure 15).

At the end of the narrative (end of the surgical journey), users were presented with a number of challenges (questions/answers, puzzles, etc) to reinforce the key messages associated with the learning objectives (Table 1). For example, users review the objects (Figure 9) and the people that are present in the surgical room (Figure 10). Moreover, users are asked about the objects in the surgical room to address learning objectives 1 and 2 (Figure 11). In addition, users are requested to identify the correct sequence of events on the day of surgery in accordance with learning objective 4 (Figure 12). Users are also tasked with choosing the correct score on the WBFPRS with various examples to address learning objectives 8 and 9 (Figure 13). Additionally, users must choose actions that are aligned with control to address learning objective 11. In each mini-game, users receive points for completing the challenges correctly (Figure 15).

Based on the number of points collected, users would enter a final “anxiety-monster” mini-game (Figure 8) after which their final score would be presented (Figure 15).

The estimated gameplay time was 20 minutes. Additional information related to the game description is documented in Multimedia Appendix 2.

Discussion

Principal Findings

This paper offers a systematic description of the ideation, design, and development of CliniPup, a serious game aimed at reducing perioperative anxiety and pain in children. Aligned with the requirements of serious game stakeholders, the SERES Framework for serious game development [47] was followed to guide the process. Using this framework and within the context of the pediatric perioperative setting, the target audience, outcome objectives, and theoretical bases were assessed and defined within scientific foundations. This evidence was used to select the game mechanics and describe the design requirements (Design Foundations). Subsequently, the Scientific and Design Foundations were explicitly translated into the serious game, CliniPup (game development and design). This high-level process is necessary to ensure that a serious game is based on strong evidence and sound change theories, which is consistent with the best practices in serious game research and development [47]. Moreover, a participatory design approach was used to ensure that the opinions and perspectives of key clinical stakeholders (surgeons, pediatricians, nurses, etc) were integrated throughout the process.

The result of this approach was the serious game CliniPup, which was developed to prepare children for surgery by delivering age-appropriate information, motivation, and behavioral skills in an engaging and fun manner. As such, CliniPup has the potential to address the limitations of existing nonpharmacological tools—cost, time, and accessibility—and differentiate them from other digital interventions, which are focused purely on distraction rather than preparation and empowerment [8,9,19,33,40].

Limitations

One limitation of the present study was that there was minimal participation from end users in the preliminary phases of design and development. The consequences of this are that children may not find CliniPup informative, believable, or fun. However, the perspectives and expertise of clinical experts in the field of pediatric surgery were consistently leveraged and a comprehensive evaluation with end users is planned for the next step. Moreover, real-world evidence was collected to supplement scientific and clinical evidence. This real-world evidence was generated through ethnographic research such as several time-motion exercises in which research nurses were shadowed on the day of surgery to ensure that a solid understanding of children and parent perspectives and experiences was collected. In addition, all learning objectives defined were not explicitly addressed with the current version of CliniPup, as it was deemed infeasible to simultaneously focus on parents’ and children’s learning objectives in a single serious game. Parental learning objectives could be implicitly addressed if parents play CliniPup with their children, but this is not expected to be an optimal mechanism. Nevertheless, the parental learning objectives could be achieved by the development of a supplementary module or educational tool focused on the parent, which uses language, visuals, content, and other tools aligned with their educational needs.

Future Research

The next step in the development process is to evaluate the current version of CliniPup with the target audience and collect their feedback on a range of factors such as usability, satisfaction, and learning experience. Data will also be collected on key clinical endpoints to develop a preliminary understanding of CliniPup’s effect in the target audience. These factors will be evaluated in a pilot trial with children undergoing ambulatory surgery and their parents. The pilot study will provide feedback on the experience of the target audience; this feedback will be leveraged to refine and improve CliniPup. Beyond this, a subsequent step is the development of a complementary tool targeted toward parents, which will ensure that all learning objectives are addressed.

Conclusions

This is the first paper to provide a comprehensive description of the ideation and development of a serious game aimed at reducing perioperative anxiety and pain in children. The development of CliniPup followed the SERES Framework for serious game development and therefore was based on strong scientific evidence and sound change theories. A key component of this approach was to generate a clear understanding of the unmet need, formulate learning objectives, and develop a serious game that can realize these objectives. As such, CliniPup can address the limitations of current nonpharmacological interventions and is different from other digital interventions such as tablet-based distraction. The usability, satisfaction, and initial clinical findings associated with CliniPup were subsequently evaluated in a pilot trial. Findings from this evaluation will inform the next steps in the serious game development process, reflecting the participatory and iterative design approach that is central to the SERES Framework for serious game development.

Acknowledgments

We thank JA and KA for their work in developing the intervention alongside MindBytes. We thank the clinicians at RZ Tienen, Campus Mariendal, and Medisch Centrum Aarschot who were involved in the game development process. MindBytes was the funding source for the development of CliniPup, which represented partial fulfillment of JA's thesis for a Master's of Biomedical Sciences at the KU Leuven, Belgium.

Conflicts of Interest

SV is a paid consultant for MindBytes, GVS is the founder and CEO of MindBytes and MindLab Interactive AI, Inc. CB is an employee of MindLab Interactive AI, Inc, and previously served as a paid consultant for MindBytes. JA, AMB, JT, and KA declare no competing financial interests. CliniPup, which is being commercialized by MindBytes, is a registered trademark owned by the Company.

Multimedia Appendix 1

Matrix of determinants, mechanisms, and learning objectives to reduce perioperative anxiety and pain in children.

[DOCX File, 90KB - games_v7i2e12429_app1.docx]

Multimedia Appendix 2

Description of game design elements implemented in the serious game CliniPup.

[DOCX File, 87KB - games_v7i2e12429_app2.docx]

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Abbreviations

GM: game mechanic
HCP: health care practitioner
IMB: Information-Motivation-Behavioral skills
LM: learning mechanic
WBFPRS: Wong-Baker Faces Pain Rating Scale

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Original Paper

Younger Adolescents' Perceptions of Physical Activity, Exergaming, and Virtual Reality: Qualitative Intervention Development Study

Nuša Faric[1], BSc, MSc; Eleanor Yorke[1], BSc, MSc; Laura Varnes[1], BSc, MSc; Katie Newby[2], BSc, MSc, PhD; Henry WW Potts[3], BA, MSc, PhD; Lee Smith[4], BSc, MSc, PhD; Adrian Hon[5], BA, MA; Andrew Steptoe[1], BA, MA, DPhil, DSC; Abigail Fisher[1], BSc, PhD

[1]Department of Behavioural Science & Health, University College London, London, United Kingdom

[2]Faculty Research Centre for Advances in Behavioural Science, Coventry University, Coventry, United Kingdom

[3]Institute of Health Informatics, University College London, London, United Kingdom

[4]Cambridge Centre for Sport and Exercise Sciences, Anglia Ruskin University, Cambridge, United Kingdom

[5]Six to Start, London, United Kingdom

Corresponding Author:
Nuša Faric, BSc, MSc
Department of Behavioural Science & Health
University College London
1-19 Torrington Place
London, WC1E 7HB
United Kingdom
Phone: 44 02067694466 ext 41914
Email: nfaric@gmail.com

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Abstract

Background: Novel strategies to promote physical activity (PA) in adolescence are required. The vEngage study aims to test whether a virtual reality (VR) exergaming intervention can engage younger adolescents (aged 13 to 15 years) with PA.

Objective: This study aimed to gather adolescents' views of using VR to encourage PA and identify the key features they would like to see in a VR exergaming intervention via interviews.

Methods: Participants were recruited through 2 schools in London, United Kingdom. Semistructured interviews were conducted with adolescents about their views on PA and what might work to increase PA, technology, knowledge and experience of VR, and desired features in a VR exergaming intervention. Data were analyzed using Framework Analysis.

Results: A total of 31 participants aged between 13 and 15 years (58% female, 62% from nonwhite ethnicities) participated in this interview study. The vast majority had no awareness of government PA recommendations but felt they should be more thoroughly informed. All participants were positive about the use of VR in PA promotion. Rewards, increasing challenges, and a social or multiplayer aspect were identified by participants as crucial aspects to include in a VR exercise game. Barriers were related to cost of high-end systems. Being able to exercise at home was very appealing. VR exergaming was viewed as a way to overcome multiple perceived social and cultural barriers to PA, particularly for girls.

Conclusions: Key elements that should be incorporated into a VR game for health intervention were identified and described. These also included the use of rewards, novelty and enjoyment in immersive game play, multiplayer options, and real-world elements, as well as continual updates and new challenge levels. The use of VR to promote PA in adolescents is promising, but some barriers were raised.

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KEYWORDS

exercise; obesity; video games; adolescent; adolescence; sports; health; leisure activities; virtual reality

Introduction

Limited Effectiveness of Physical Activity Interventions in Adolescents

The health benefits of performing sufficient physical activity (PA) are well established and include reduced risk of noncommunicable diseases, reduced risk of premature mortality, and better mental health [1-3]. There is a dose-response relationship between PA and health with a 20% to 30% reduction in chronic illness and premature death for those that meet PA guidelines [1-3]. Adolescence (13 to 17 years) is a key time to intervene, as long-term PA likely confers maximum protective benefit [3]. Those who have high levels of PA in adolescence are more likely to be active in adulthood and lead healthier lifestyles [4,5]. There are psychological and social benefits of increased PA participation in adolescence [6]. However, less than 15% of boys and 10% of girls are achieving the UK government recommendation for adolescents of at least 60 min of moderate-to-vigorous physical activity (MVPA) per day [7]. Levels of adolescent PA are similarly low in other developed countries [8]. Without intervention, activity levels decline by around 7% per year throughout adolescence, particularly in girls [9]. Strategies to increase PA in this group are urgently required.

It remains unclear what works best to change adolescent PA behavior [10,11]. A recent review of digital PA interventions for adolescents recommended that education, goal setting and feedback, self-monitoring, and parental support should be incorporated [12].

Despite recommendation that conducting formative work with target users is important to intervention development [13,14], very few PA interventions have involved adolescents in development. Before developing a school-based intervention, Corder et al conducted focus groups with participants aged between 16 and 18 years and identified choice, novelty, mentorship, rewards, competition, and flexibility as key aspects that young people would like to be included [15]. Although co-design or participatory design (PD) of digital health interventions is not necessarily recommended (as no higher effectiveness was found for games developed with PD), user input is beneficial [16]. This is particularly applicable when considering digital PA interventions [16].

Digital Physical Activity Interventions in Adolescents

Digital interventions are likely to be particularly appealing for adolescents; more than 90% play video games for at least an hour per day [17]. A variety of exergames are available and many have been commercial successes: Wii Fit sold over 22 million copies worldwide in its first 4 years [18]. More recently, an augmented reality exergame run on smartphones, Pokémon Go, has seen over 800 million downloads [19]. A study conducted in Hong Kong (participants N=210; aged 16 to 64 years) found that the use of Pokémon Go was associated with a short-term increase in the players' daily walking and running distances, particularly in those who were less physically active [20].

Levels of PA and physiological response when exergaming are comparable with field-based PA, and significantly increased when compared with standard gaming [21]. Exergames also enhanced enjoyment, self-efficacy, and motivation for PA [21]. Exergaming interventions can lead to weight loss in overweight adolescents [22,23]. However, past research has generally involved small studies and earlier generation exergames.

Virtual reality (VR) has the potential to enhance the exergaming experience through immersion and presence contributing to the feeling of absorption, flow, and fun [23,24]. New generation VR technologies deliver increasingly realistic experiences at decreasing cost. Some small laboratory-based studies in adults have found that immersive VR exergames resulted in the same or higher intensity of exercise as standard exercise conditions, but with higher ratings of enjoyment and interest [25,26]. One study also found that perceived exertion was lower and self-efficacy was higher during VR cycling compared with standard stationary cycling [27]. An exploratory pre-post study including 9 children and adolescents suggested that an immersive VR game enhanced motivation to be active [28]. Immersion is likely to distract participants from exertion and possibly negative thinking during PA.

We hypothesized that a VR exergaming intervention could increase PA in adolescents. The aim of this study was to interview adolescents about their recommendations for a PA intervention, use of technology, gaming, and interest in VR for PA.

Methods

Participants

Participants were recruited from 2 secondary schools in London, United Kingdom between January and July 2017. To be eligible, participants had to be aged between 13 and 17 years. Given the need to recruit a high number of girls, one was a girl's school whereas the other was mixed. Both schools were in areas of high ethnic and socioeconomic diversity. Each school sent information packs home with students from 2 classes. In total, approximately 65 packs were sent to the interested students. Interested students each returned and completed the parental consent and child assent form. We aimed to interview approximately 30 young people based on guidance provided by Fugard and Potts [29] and we interviewed all students who returned the completed consent forms.

Ethics

Ethical approval was provided by the University College London Ethics committee (Project ID 10213/001) with all participants and their parents/caregivers providing informed written consent.

Qualitative Interviews

We used a semistructured interview. We asked the following: "What is the amount of time you spend being active as well as inactive per week in hours?"; "What is your average sitting time per day?"; "Do you know about the recommended guidelines for PA in your age group?"; What might encourage people of your age to become more physically active?"; "What is your current technology use- what do you use and how long per day or week?"; "What interest you about a particular game?"; "Do you know much about VR?"; "What are your experiences and/or opinion on using VR?"; "Do you use any other health-related technology?"; and "How would you help increase PA through use of technology and VR?". Finally, participants were asked about key features desired in a VR exergame. Interviews were conducted face-to-face in schools between June and July 2017 by 2 researchers (EY and LV) and transcribed verbatim.

Analysis

Framework Analysis was used, which is a flexible and systematic approach for analysis of semistructured interviews [30]. A total of 2 researchers (EY and LV) independently analyzed 3 transcripts, each developing an initial set of codes. The participant's responses within the interviews were assigned codes and coded into a framework matrix, along with relevant quotes to make it visually straightforward and easy to track. Then 2 additional researchers (NF and AF) independently interpreted the data to identify common themes among responses. Theme prevalence was not determined quantitatively but instead grouped together into main themes described below. All researchers then met and discussed their interpretations and codes, compared them, and made minor adjustments to create the final framework. The final interpretations are shared below, with illustrative quotes (followed by participant's gender and age).

Results

Overview

A total of 31 participants aged between 13 and 15 years were interviewed. Of them, 58% (18/31) were girls. Participants identified their ethnicity as white British (n=7), white other (n=5), multiple ethnicities (n=5), Asian (n=5), Indian (n=2), Bangladeshi (n=2), Pakistani (n=1), Caribbean (n=1), African (n=1), and black (n=2). Interviews lasted for 40 to 70 min (mean 55 min). The themes were apparent and straightforward with no disagreements between the researchers. The main themes and their subthemes are described in Table 1.

Table 1. Identified main themes and subthemes.

Main theme	Subthemes
PA[a] and sedentary time	Adolescents were not aware of the PA guidelines for people of their age or of all health benefits associated with PA or consequences of not performing sufficient PA
General technology use	Smartphones were the technology most used by adolescents for recreation; Gaming was popular and exergames were a positive past experience, but some games were no longer played (eg, Just Dance or Pokémon Go)
Exergaming	Exergames were seen as a fun, motivating, and encouraging movement covertly; There was a strong appeal of exercising at home and overcoming cultural or social barriers, particularly for girls; Exergames were not seen as a replacement if already involved in sport
Experience of VR[b]	Positivity toward VR but limited experience; Whole body movement, presence, and novelty appealing in VR; Barriers with VR included bulky headsets, addiction, and price; Perceived parental concern about using VR for PA; Simple public health messages about screen time preferred

[a]PA: physical activity.

[b]VR: virtual reality.

Physical Activity and Sedentary Time

Adolescents Were Not Aware of the Recommended Guidelines for Physical Activity and of All Health Benefits and Risks Associated With Physical Activity

Awareness of PA recommendations for adolescents was very low with 94% (29/31) participants guessing the recommended guidelines. The intensity or resistance exercises were not mentioned. Participants felt strongly that people of their age *should* be informed of PA recommendations and the links between PA and health. Girls in particular reported this knowledge as a key motivation for being active and felt this would increase activity in their peers:

> *Give [young people] some of the risks that could happen in the future if you do not keep fit and not healthy.* [F, 14]

When probed about how they might like this information delivered, the consensus was visually:

> *Maybe videos on how to do it because I don't think people [my age] really take in facts.* [F, 14]

But tangible rewards were also important motivators for PA:

> *So there's something to work for instead of just saying do it and you'll be more active. You have to give them something at the end. Anything people my age will find fun. Probably mostly money.* [M, 15]

General Technology Use

Mainly Smartphones, Mainly for Recreation

All participants used technology up to 6 hours per day (eg, smartphone and computer), mainly for recreational uses (eg, gaming and social media) but also practical (eg, homework). Boys used technology mainly for gaming, whereas girls used technology for watching videos, listening to music, and socializing (reported logging into social media between 30 and 55 times per day). There were positive and negative perceptions of technology related to PA:

> *I saw this report, kids nowadays are more overweight compared to before, and that's probably because we're always just sitting down on our phones, tablets and stuff.* [F, 14]

> *[use technology to encourage people to go outside] because obviously with technology people don't go outside as much as they used to. So, I don't know, you just need to get people out. Because the phone is so interesting.* [F, 15]

Gaming was Popular and Exergames Were a Positive Past Experience

The majority of participants engaged in some type of gaming. Games played were diverse, but common features were continual challenges/levels of difficulty, rewards, competition, social aspects, and story modes. A total of 5 participants specifically mentioned games that were simple, slow to build, and ongoing as leading to playing for a number of years. Exergames were often mentioned; all participants had played them, and they were generally described positively, but always in the past tense such as Just Dance (Nintendo Wii):

> *I really liked that [Just Dance] but I don't know, it just died out for some reason, I don't know why. We had the dancing thing, to step on it, all that kind of stuff, yes. Yes, that was sick.* [F, 15]

Pokémon, Gone

Many participants described Pokémon Go (released in July 2016) as something they had tried but no longer used, with some stating technical reasons as off-putting:

> *It was really fun in the beginning, but then the servers were overwhelmed with too many people playing.* [M, 14]

> *[I played it] only once then found out it used up most of my data.* [F, 13]

Many mentioned safety concerns preventing use (Web-based security, road safety, and getting lost), often reflecting on negative stories they had heard in the media. Others felt it had increased their PA, but still referred to it is as a previous experience:

> *Well, at the time where it was big it was really cool because it actually made me go outside and look around and stuff. It did made me walk a lot more.* [F, 14]

Exergames: Fun, Motivating, and Encouraging Movement Covertly

Exergames were viewed as appealing because they were fun, motivating, and good ways to encourage incidental PA:

> *I think it's good because some people may think that, "I don't want to do this sport," but actually, they are, without realising.* [F, 15]

> *It's way better because you're working out but you're having fun and you don't realise you're working out.* [F, 14]

Social benefits and competition when exergaming were also described as appealing:

> *It's nice because other people can actually watch it at the same time, it's not just one person involved in it. So, it makes it fun and motivates the person to even try harder, so it creates competition as well.* [F, 15]

Strong Appeal of Exercising at Home and Overcoming Cultural or Social Barriers

Participants particularly liked the idea that exergames allowed activity in the home:

> *Getting fit isn't always enjoyable and it could also make you confident to do it[...] You can do it in the privacy of your own home.* [F, 14]

> *Virtual reality...in your own home because people like going running but sometimes people can't...my parents don't always let me out, so doing it in my own home...Yes. And also for Muslims, you have to cover your body, so it's hard to go running while covering your body, whereas at home it's very easy.* [F, 14]

Exergames Not a Replacement if Already Involved in Sport

However, those who were already involved in sport tended to think exergames should not be a replacement:

> *I think they're useful, but I think it's better for people to actually do sport.* [F, 14]

Experience of Virtual Reality

Positivity Toward Virtual Reality but Limited Experience

Nearly all participants were extremely positive about the idea of using or trying VR. More than half had tried some kind of VR (usually smartphone-based headsets). There were no apparent gender differences in wanting to try, having tried, or liking VR. A total of 6 participants described having tried a one-off fully immersive experience in an external venue, and 1 had high-end equipment at home. Very few had any kind of VR equipment at home, and if they did, it was usually referred to as being owned by a parent or older sibling. Participants wanted to own it but felt the price was prohibitive:

> *I've used it once when I went to a big shopping centre. I thought it was quite cool but then I looked at the price: thousands.* [M, 15]

Whole Body Movement, Presence, and Novelty Appealing in Virtual Reality

Those who had tried VR were positive about it, describing it frequently as *cool*, *exciting*, *fun*, and highlighting the whole body movement, presence, and novelty as appealing. Only 1 participant thought it was *pointless* (F, 14).

> *You're actually in the game, you can feel you're moving with it, it's not just your fingers and your eyes, it's your whole body is involved so it's more involved.* [F, 15]

> *I think it's absolutely cool. For [named a standard games console], you sit in front of a TV, but now when*

> *it actually feels like you're there, it makes it way more interesting and fun.* [F, 15]

Other benefits were raised such as widening understanding/experience or creating safe spaces to try new activities:

> *It is like being in real life, but safer, if you know what I mean. Like if you do something serious, it is not real. So, in a way, it is safer to learn things.* [F, 14]

Barriers With Virtual Reality Included Bulky Headsets, Addiction, and Price

There were technical barriers including the size and weight of the headset. Barriers were usually countered with belief that these issues would be addressed as the technology advanced:

> *I think it's a great concept, but I think it has a way to go. It's not really developed as much yet...Because right now you have to wear like a massive headset that's really heavy and you have to move around and it's not as receptive of the little controls.* [M, 15, owned VR headset]

As with other types of gaming, a prominent concern was fear of addiction:

> *Just as they're addicted to PlayStation and all of that, they would be addicted to this game.* [F, 14]

Some participants described physical symptoms of use, such as nausea, dizziness, headaches, and fear of bumping into others. However, nearly all believed that VR was going to be extremely popular in the future:

> *I think virtual reality is the future of technology and it will be more involved in everyday life.* [F, 14]

Perceived Parental Concern About Using Virtual Reality for Physical Activity

Although participants felt positively about a VR exergaming intervention, there was a perception that parents might not be supportive:

> *Some parents would be really opposing to it. Just because I know some of my friends, their parents don't like them being on electronics at all.* [F, 14]

> *Parents wouldn't buy that for their children because obviously price.* [M, 13]

Simple Messages About Screen Time Preferred

When asked about how to counteract potentially conflicting public health messages around reducing screen time versus introducing an exergaming intervention, the consensus among participants was that providing information would be sufficient. Many said things like *just tell us* (that screen time needs to be limited; M, 15) or suggested that it was sitting rather than screen time that was the issue:

> *I would say if it's in front of a screen and it does encourage physical activity, it doesn't really matter that it's in front of a screen, as long as you're engaging.* [M, 14]

In addition, this approach could appeal to gamers, who were perceived to be sedentary:

> *They're [gamers] probably more interested in video games, so the virtual reality might encourage them more [to be physically active].* [F, 14]

This view was supported by participants who identified as gamers:

> *Because it's a game. Immediately I hear game, personally, I'm into it already and think it will be more exciting.* [M, 13]

Additional features that participants reported they would like to see in a VR exergame are shown in Table 2 with supporting quotes.

Table 2. Desired features of virtual reality physical activity intervention.

Features to incorporate	Quote(s)
Include smartphone-based elements	"An app [for a PA[a] intervention], because more people have a phone than virtual reality" (F, 14)
Use a popular accessible activity such as dancing/whole body movement	"I would probably start with just people getting into dancing, because everyone quite likes that and enjoys that" (F, 14); "Something with dancing would be fun, because obviously you have to move your whole body instead of just your arms or your legs" (F, 13)
Regular updates to prevent boredom	"Update it every month so there's something new every month so it doesn't get boring" (M, 10)
Break tasks to prevent addiction	"It could give you tasks on there. It could be like, 'Go outside and find the tallest tree,' or something. It could encourage you to go outside" (F, 13)
Rewards and prizes	"I would design something like... in the game, if you played the [sport] in real life you'd get a massive prize" (F, 13)
Competition	"Something competitive. People are really competitive in school, so something they can really get into and play as a team" (M, 15)
Multiplayer option	"I would probably try and get all my friends involved first, because you don't really want to do it alone" (F, 14); "You need it to be with more people. You don't want to be alone" (F, 13)
Real world elements	"I think it's a good starting point, definitely for people who can't go for a run or something. [...] But I would still say going outside is always better" (F, 14)
VR[b] gaming clubs or meet-ups	"There'd be a club where you bring your VR, and it would be at an affordable price, where you can bring it and do it with people" (F, 13)

[a]PA: physical activity.

[b]VR: virtual reality.

Discussion

Principal Findings

Our findings suggest strong support for the potential of VR to promote PA in adolescents. However, there were a number of factors relevant to researchers developing any digital PA intervention discussed below.

Participants raised the importance of parental support, in line with previous research on digital health interventions for adolescents and studies exploring determinants of adolescent PA [12]. We are separately interviewing parents and teachers about their perceptions of VR exergaming and PA.

Awareness of any government guidelines around PA was low but desire for knowledge was high. Our participants (particularly girls) felt that an educational component would be desirable, and presenting information about benefits of PA in a visual format was recommended. This is in line with our previous work suggesting less than 20% of parents knew the government PA guidelines for their children [31]. A review of 17 adolescent PA trials found that education alone did not result in behavior change. However, multicomponent studies incorporating education found strong effects on PA [10]. Multicomponent studies can be labor intensive (eg, requiring alteration of environmental infrastructure), so their potential for wide-scale implementation is questionable. The present *digital revolution* and the ubiquity and frequency of technology use by adolescents, highlighted in our study, has greatly increased potential reach.

Rewards were suggested as being important to encourage PA engagement (particularly in boys, but also for some girls), in line with previous studies [15,32]. The rewards suggested were always material (usually financial). Financial rewards are effective in motivating PA in adults [33], and a trial using incentives and gamification to promote PA in families had positive effects [34]. In line with theories such as the self-determination theory, fun and enjoyment are intrinsically motivating and key motivators for gaming [35], and most adolescents engage in gaming without a material reward. Fun was consistently reported as a reason for engaging in exergaming by our participants.

Appeal of Home-Based Physical Activity

Our data suggest that a home-based PA digital intervention is appealing to our target population. Most previous interventions targeting adolescent PA have been at least partially delivered in schools, but a more recent cohort found 70% to 81% boys and girls said they would choose to be active at home or in a gym/leisure center, as opposed to in school or outdoors [32]. Particularly for the girls in our study, home-based PA had the potential to overcome cultural and social barriers. In addition, they were viewed as appealing because they harnessed behaviors (such as gaming) that were already being performed. Many suggested including additional intervention elements such as community-based meet ups or groups to enhance the social elements and foster competition. In the aforementioned quantitative survey, adolescents also reported they would choose to be active with their friends (over, eg, family) [32]. However, some girls in our study felt the ability to exercise privately in their own home was appealing, so an optional social element would be best.

Potential for Virtual Reality Interventions

At the time of writing this paper, the cost of the high-end VR equipment required to create a fully immersive exergaming experience was prohibitive (around £2000 for the equipment and necessary computer), and this was recognized as a barrier by our participants. However, participants expect costs to fall.

This is likely and ownership will increase [36]. We are aware that the novelty, reported as important in our study and others [15], will therefore also diminish. This strengthens the argument for developing a digital intervention within a theory-based framework, so the active ingredients can be replicated using other platforms in future. This also emphasizes the importance of making digital interventions intrinsically fun and enjoyable so that they are not reliant only on novelty. Indeed, in our study the participants who were most positive were those who had tried VR.

Our study had specific and narrow aims and around 60 min worth of discussion per participant. Interviews were conducted by researchers experienced in working with adolescents. Therefore, we believed our sample size held sufficient information power to address the research questions [37].

Our participants desired continual updates and additional challenge levels, and these are key elements of gaming that can map to specific behavior change techniques in a digital health intervention [38]. Embedding the digital platform at the center of a multicomponent intervention, and working with professional developers who understand how to keep a game engaging and challenging, is therefore crucial for success.

Limitations

The results were obtained from a reasonable number of participants in comparison with other studies using thematic analysis [29], with a diverse range of ethnicities and more girls than boys. It is possible that those who were more interested in health agreed to participate. However, as less than 10% to 15% of the UK adolescent population meet PA recommendations [7], it is very unlikely that we only recruited active participants. The focus on technology as well as PA was also likely to attract a mix of interests. All participants were aged between 13 and 15 years, and results may have been different if opinions were from older adolescents. It is likely that our intervention will target younger adolescents given the value in intervening early (VR gaming is not recommended in those younger than 13 years). We will also continue to work with our public engagement groups and adolescent steering committee to gather information from adolescents from diverse backgrounds.

Conclusions

The results of this study suggest that an intervention to promote PA in adolescents that has VR exergaming at the core is promising. However, it is likely that additional elements will be required to produce sustained behavior change including educational elements, tangible rewards, prompts to encourage breaks, and parental support.

Acknowledgments

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Conflicts of Interest

This research is sponsored by the Medical Research Council industry partnership grant and leads to development of a VR game licensed by Six to Start. There is no legal, financial, or commercial conflict with our industry partner company, Six to Start.

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Abbreviations

PA: physical activity
PD: participatory design
VR: virtual reality

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Original Paper

Effects of the FIT Game on Physical Activity in Sixth Graders: A Pilot Reversal Design Intervention Study

Damon Joyner[1], PhD; Heidi Wengreen[2], PhD; Sheryl Aguilar[2], MS; Gregory Madden[2], PhD

[1]Weber State University, Ogden, UT, United States

[2]Utah State University, Logan, UT, United States

Corresponding Author:
Heidi Wengreen, PhD
Utah State University
8700 Old Main Hill
Logan, UT,
United States
Phone: 1 435 797 1806
Email: heidi.wengreen@usu.edu

Abstract

Background: The FIT Game is a low-cost intervention that increases fruit and vegetable consumption in elementary school children. For this study, the FIT Game was adapted into an intervention designed to increase children's physical activity at school.

Objective: We aimed to evaluate if the FIT Game could increase children's physical activity relative to their baseline levels.

Methods: A total of 29 participants were recruited from a sixth-grade classroom. An ABAB reversal design was used. Participants wore an accelerometer while at school during pre/postintervention baseline (A) and intervention (B) phases. During the FIT Game intervention, daily physical activity goals encouraged the class to increase their median daily step count above the 60th percentile of the previous 10 days. When daily goals were met, game-based accomplishments were realized.

Results: Children met their activity goals 80% of the time during the intervention phases. Physical activity at school increased from a median of 3331 steps per day during the baseline to 4102 steps during the FIT Game phases ($P<.001$, Friedman test).

Conclusions: Preliminary evidence showed that playing the FIT Game could positively influence children's physical activity at school.

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KEYWORDS

children; accelerometer; step count

Introduction

The prevalence of obesity has increased in recent years, and this condition affects more than one-third of children in the United States [1]. Childhood obesity has negative health consequences both during childhood [2-4] and, if not ameliorated, throughout the lifespan [5,6]. Meeting the recommended guidelines for daily physical activity (PA) reduces the risk for overweight, obesity, and chronic disease [7,8]. Increased activity also improves cardiorespiratory fitness, flexibility, and muscular strength [9]. These benefits extend into adulthood because childhood PA levels are predictive of adult PA levels [10-12]. Despite these short- and long-term benefits, PA declines from ages of 6-19 years [13], and many children in the United States do not meet the recommended 60 minutes of daily moderate to vigorous PA [8,14,15].

Addressing this public health crisis should include school-based interventions because most children in the United States spend 6-8 hours a day, 5 days a week, in school. As such, effective school-based interventions have the potential to help children develop healthy PA patterns that become habitual (ie, consistent daily initiation of PA without having to consciously remember to do so [16]). Within the public-school setting, interventions most likely to be widely adopted are those that positively influence healthy behavior while incurring minimal material and labor costs.

With these goals and constraints in mind, our research group developed the FIT Game, a low-cost game-based intervention designed to increase fruit and vegetable intake in elementary-aged children [17-19]. This intervention uses equipment already present in elementary schools in the United States (computer and projector) and employs video game design principles to motivate healthy eating. Because the FIT Game has consistently produced significant increases in healthy eating among children at school [17-19], we aimed to adapt it to the goal of increasing PA at school. In this single-case experiment, the FIT Game was played over 20 days with PA goals instead of healthy-eating goals. The experiment was conducted as a pilot study preliminary to future studies of more rigorous design.

Methods

Recruitment

All students (n=29) enrolled in the selected sixth-grade classroom were invited to participate. The classroom was selected because it was convenient and located in an elementary school in the Cache County, UT, school district. All the children in the selected classroom, and their parents/guardians, provided written consent to participate. The students were healthy and without physical disabilities that would constrain mobility. Of the students, 90% were Caucasian, 59% were female, and 26% of the children attending the school qualified for free or reduced lunch. All procedures were reviewed and approved by the Institutional Review Board for the Protection of Human Subjects at Utah State University.

Instruments

Each child was assigned a unique wrist accelerometer (Fitbit Flex, San Francisco, CA). Students were instructed to wear the accelerometer on their nondominant wrist. The Fitbit Flex provides reliable PA data by reporting daily step counts [20]. As per the standard Fitbit function, tapping the accelerometer face produced illuminated dots, each representing 2000 steps, to a maximum of five dots, although children were not informed of this function or the meaning of the dots prior to the intervention. A projector available in the classroom was used to show FIT Game episodes on a screen in the front of the room. Each episode was accessed through Google Slides, cycled through the slides automatically, and lasted approximately 2 minutes. A personal computer equipped with Fitbit Connect (Fitbit Flex) was used to sync children's accelerometers with their online Fitbit accounts.

Intervention

The intervention was based on the FIT Game, which has been previously used to increase fruit and vegetable consumption of elementary school children [17-19]. The FIT Game is a science-fiction narrative in which the Field Intensive Trainees (the FITs) are tasked with finding and capturing three villainous members of the Vegetation Annihilation Team (VAT) before they can cause planetary destruction. The object of the game for the sixth-grade players was to help the FITs complete this task.

The comic book–formatted FIT Game narrative was presented in slideshow episodes, with a different episode presented each day when PA goals were met the previous day; episodes were displayed on a screen approximately 15 minutes before recess. The top panel of Figure 1 shows one of the narrative slides, and the bottom panel shows a slide in which two of the FITs encourage the sixth-grade participants to help the FITs by being a little more active.

When the intervention began (see below for Experimental Design), children were informed that the object of the game was to help the FITs capture the three members of the VAT. Children were also informed that by collectively meeting or exceeding a daily PA goal, they could assist the FITs by providing them with FIT energy. FIT energy, the children were informed, enabled the FITs to power their ship and other equipment within the narrative of the game. When PA goals were met on day X, the next slideshow episode was shown on day X+1. Thus, the intervention was incentive based such that when the incentives were earned, they were realized within the FIT Game episodes (eg, capturing one of the villains or obtaining a needed piece of equipment).

During the intervention, PA goals were met if the median-per-student step count was at or above the 60th percentile of the preceding 10 days of step counts; for example, on day 11, the goal was the 60th percentile of the median step counts on days 1-10, whereas on day 12, the goal was the 60th percentile of step counts on days 2-11. This percentile schedule of reinforcement [21] uses a moving window of the prior 10 days' performance to adjust the difficulty of the goal to the current ability of the player (ie, the class). When the PA goals are met, the percentile schedule gradually increases the goal. This maneuver prevents the game from becoming too easy while maintaining a constant difficulty level (at the 60th percentile) throughout the intervention. Likewise, if the children fail to meet their goal, the percentile schedule decreases the next PA goal to reduce the probability that players will become frustrated with persistent failures. On days when the PA goal was not met on the previous day, a new episode was not presented; instead, the teacher informed the students that the next episode would not be presented until they met their goal (which, unbeknownst to them, was adjusted by the percentile schedule of reinforcement). Over the course of the intervention phases (see below for Experimental Design), the class helped the FITs foil the plans of the VAT, find and capture the villains, and save their school in a "boss battle" against the leader of the VAT.

Figure 1. Two sample slides from a FIT Game episode. In the slide prior to the top panel, the villain (shown in the background saying, "Deal with that sucker!") summoned a group of zombies to prevent the mechanical-legged hero from catching the villain. While the hero is initially confident that his "Turbo Legs can outrun these zombies," a subsequently revealed voice bubble indicates that he needs energy. The next slide (lower) encourages the children to be a little more active, so that the hero can obtain the energy he needs.

Experimental Design

A single-case experimental design was employed; specifically, the ABAB reversal design, with "A" referring to pre/postintervention baseline phases and "B," to the FIT Game phases. This experimental design establishes internal validity by repeatedly manipulating the independent variable and documenting that behavior changes systematically between phases [22-24]. Throughout the experiment, the classroom teacher instructed children to put on their accelerometer in the morning upon arrival (8:30 am) and take it off just before leaving school (2:30 pm); thus, PA levels reported are restricted to activity during school hours. During evening hours, study personnel collected data from each accelerometer and charged it as necessary. Prior to the first baseline phase, students wore the accelerometer for 5 days. This was designed to acclimate children to the device and to reduce the probability of reactivity.

Baseline 1 (Days 1-10, 2 School Weeks)

During the Baseline 1 phase, children wore their assigned accelerometers, as described above. The teacher provided no encouragement for children to be more active nor were the children informed of their individual step counts.

FIT Game Phase 1 (Days 11-20)

During this phase, procedures continued as outlined in Baseline 1, except that the FIT Game intervention was implemented with daily PA goals and game episodes, when earned (see Intervention section above).

Baseline 2 (Days 21-30)

On day 21, children were informed that the game would pause for 2 weeks, as the FITs traveled through a wormhole in space, temporarily blocking communication. During Baseline 2, data collection continued in the manner described in Baseline 1.

FIT Game Phase 2 (Days 31-40)

On day 31, the game resumed where it left off, with a new episode presented to the class. As in the prior FIT Game phase, PA was measured daily and new episodes were contingent upon meeting PA goals set in the manner described above.

Statistical Analysis

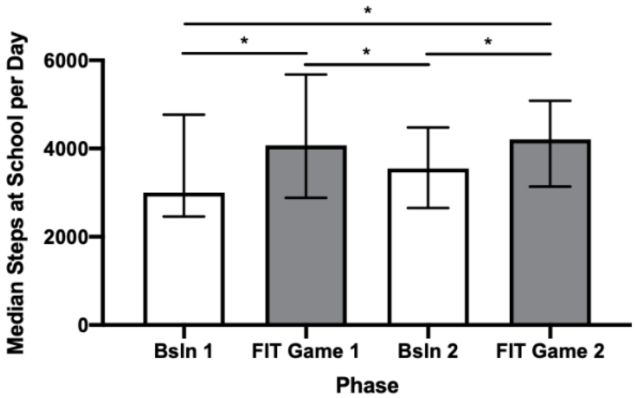
Shapiro-Wilk tests indicated that distributions of step counts deviated from normality at the baseline (W=0.92; P=.03) and during the intervention (W=0.93; P=.056). Therefore, the Friedman test (nonparametric equivalent of a repeated-measures one-way analysis of variance) was used to determine if differences existed between phases. Comparisons between phases were made using Bonferroni corrected posthoc Wilcoxon matched-pairs signed rank tests (α=0.0083). Effect size was calculated as $r=Z/\sqrt{N}$, with values of 0.1, 0.3, and 0.5 commonly interpreted as small, medium, and large effect sizes, respectively [25]. All analyses were conducted using Prism 8.0 for Mac (GraphPad Software Inc, San Diego, CA).

Results

Figure 2 shows the median (and interquartile range) steps taken per child per day during the baseline and FIT Game phases.

Children met their PA goals on 16 of the 20 days (80%) of the FIT Game phases, increasing their median step counts from 3331 per day during baseline to 4102 per day during the FIT Game phases (X^2=39.0; *P*<.001) . From Baseline 1 to FIT Game phase 1, PA increased significantly by a median of 1073 steps per child per day (*W*=425; *P*<.001; *r*= 0.603). During Baseline 2, the average number of steps significantly decreased from levels observed in FIT Game phase 1 (*W*=399; *P*<.001; *r*= 0.566), thereby demonstrating experimental control over PA. When the game resumed in FIT Game phase 2, the PA increased significantly above Baseline 2 levels by a median of 658 steps (*W=343*; *P*<.001; *r*= 0.487). Step counts during FIT Game Phase 2 were also significantly higher than Baseline 1 by a median of 1204 steps (*W*=335; *P*=.001; *r*= 0.476) . When individual students' step counts were summed across their two baseline phases and then across their two FIT Game phases, all 29 students increased their PA levels while playing the FIT Game (range: 128-3476 steps; binomial test *P*<.001).

Figure 2. Median (interquartile range) number of steps taken during school hours during baseline and while playing the FIT Game. Bonferroni post-hoc Wilcoxon matched-pairs signed rank test. *P<.001. Bsln: baseline.



Discussion

This pilot study illustrated that the FIT Game could be successfully adapted to increase PA at school instead of healthy eating at school. The FIT Game significantly increased PA in sixth-grade students by a median of 771 steps per day at school during the FIT Game phases of the intervention. While the clinical utility of this increase is modest, it should be evaluated in the context of limited opportunities for improvement: Children wore their accelerometers only at school and had only 20 minutes of recess per day. Given the large effect size of this study (median effect size across comparisons: *r*=0.533), future research should evaluate if the FIT Game can produce clinically significant increases in PA (eg, 60 minutes of moderate-to-vigorous activity each day) when accelerometers are worn at school and at home and over a longer period of time. Such an intervention may prove useful in slowing or reversing the reduction in PA that occurs from ages of 6-19 years [13].

Reviews of school-based PA interventions provide a mixed picture of efficacy, with modest effects overall and an overreliance on parent/child self-reports of activity at home [26-28]. Most interventions are designed using Social Cognitive Theory, and some have called for new, goal-based theoretical approaches for developing effective, low-cost, scalable interventions [27]. The FIT Game was developed using operant learning theory and dynamic goal-setting, in which the reinforcement contingency continuously adapts to the "skill" of the player [21]. Reinforcement-based interventions have increased healthy eating in elementary school–aged children, both during the intervention phase and at follow-ups of up to 1 year [29,30]. Therefore, evaluating the longer-lasting effects of the FIT Game on PA outcomes is an important area for future research.

Three limitations of this study are noteworthy. First, from a clinical perspective, it is discouraging that the PA returned to baseline levels when the game was suspended during Baseline 2. We anticipated such decreases, and they were needed to demonstrate the efficacy of the FIT Game within the logic of the single-case experimental design [23]. To address this limitation, future research should employ a cluster randomized design and evaluate the ability of a longer-duration version of the FIT Game to produce behavior change during not only the intervention, but also the postintervention follow-up. Some evidence suggests that health behavior change takes approximately 10 weeks to become habitual [16], suggesting a minimum target for intervention duration. Within the healthy eating literature, long-term interventions using goals and incentives have produced encouraging outcomes [31]. In this pilot study, the FIT Game was played for only 2 weeks before reverting to baseline conditions; therefore, the reversions to baseline PA levels are not surprising.

Second, the study is limited in sample size (N=29) and demographic diversity of the sample (predominantly Caucasian sixth graders living in Northern Utah). Future studies should evaluate the efficacy of the FIT Game on PA in multiple classrooms with more diversity than is represented in this study.

Such a study should also attempt to address the third limitation of the present study: PA was measured only during school hours. Practical limitations necessitated this arrangement, as the Fitbit software would not reliably sync all 29 Fitbits during the school day. Solving this measurement issue could positively influence physical activity at home and school, and this is likely to have a larger impact on individual health.

In summary, this project provided initial evidence that the low-cost and low-labor FIT Game could be used to significantly increase elementary school children's daily levels of PA. Future research should explore if larger increases in PA can be encouraged and maintained over longer intervention phases, as this may produce habitual patterns of activity that could carry on through adulthood. Future research should also explore combining the two versions of the FIT Game, developing one game that simultaneously increases healthy eating and PA each day. Such a low-cost intervention could significantly impact public health if it were widely adopted in developed nations facing a childhood obesity epidemic.

Acknowledgments

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Conflicts of Interest

None declared.

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Abbreviations

FIT: Field Intensive Trainee
PA: physical activity
VAT: Vegetation Annihilation Team

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Original Paper

Search and Match Task: Development of a Taskified Match-3 Puzzle Game to Assess and Practice Visual Search

Alvin Chesham[1], MSc; Stephan Moreno Gerber[1], MSc; Narayan Schütz[1], MSc; Hugo Saner[1,2], MD; Klemens Gutbrod[3], PhD; René Martin Müri[1,3], MD; Tobias Nef[1,4], PhD; Prabitha Urwyler[1,4], PhD

[1]Gerontechnology & Rehabilitation, University of Bern, Bern, Switzerland

[2]Department of Cardiology, University Hospital (Inselspital), Bern, Switzerland

[3]Department of Neurology, University Neurorehabilitation, University Hospital Bern (Inselspital), University of Bern, Bern, Switzerland

[4]Artificial Organ Center for Biomedical Engineering Research, University of Bern, Bern, Switzerland

Corresponding Author:
Tobias Nef, PhD
Gerontechnology & Rehabilitation
University of Bern
Murtenstrasse 50
Bern, 3008
Switzerland
Phone: 41 31 632 76 0
Email: tobias.nef@artorg.unibe.ch

Abstract

Background: Visual search declines with aging, dementia, and brain injury and is linked to limitations in everyday activities. Recent studies suggest that visual search can be improved with practice using computerized visual search tasks and puzzle video games. For practical use, it is important that visual search ability can be assessed and practiced in a controlled and adaptive way. However, commercial puzzle video games make it hard to control task difficulty, and there are little means to collect performance data.

Objective: The aim of this study was to develop and initially validate the search and match task (SMT) that combines an enjoyable tile-matching match-3 puzzle video game with features of the visual search paradigm (*taskified game*). The SMT was designed as a single-target visual search task that allows control over task difficulty variables and collection of performance data.

Methods: The SMT is played on a grid-based (width × height) puzzle board, filled with different types of colored polygons. A wide range of difficulty levels was generated by combinations of 3 task variables over a range from 4 to 8 including height and width of the puzzle board (set size) and the numbers of tile types (distractor heterogeneity). For each difficulty level, large numbers of playable trials were pregenerated using Python. Each trial consists of 4 consecutive puzzle boards, where the goal of the task is to find a target tile configuration (*search*) on the puzzle board and swap 2 adjacent tiles to create a line of 3 identical tiles (*match*). For each puzzle board, there is exactly 1 possible match (*single target* search). In a user study with 28 young adults (aged 18 to 31 years), 13 older (aged 64 to 79 years) and 11 oldest (aged 86 to 98 years) adults played the long (young and older adults) or short version (oldest adults) of the difficulty levels of the SMT. Participants rated their perception and the usability of the task and completed neuropsychological tests that measure cognitive domains engaged by the puzzle game.

Results: Results from the user study indicate that the target search time is associated with set size, distractor heterogeneity, and age. Results further indicate that search performance is associated with general cognitive ability, selective and divided attention, visual search, and visuospatial and pattern recognition ability.

Conclusions: Overall, this study shows that an everyday puzzle game–based task can be experimentally controlled, is enjoyable and user-friendly, and permits data collection to assess visual search and cognitive abilities. Further research is needed to evaluate the potential of the SMT game to assess and practice visual search ability in an enjoyable and adaptive way. A PsychoPy version of the SMT is freely available for researchers.

(JMIR Serious Games 2019;7(2):e13620) doi:10.2196/13620

KEYWORDS

match-three puzzle games; video games; task difficulty; attention; pattern recognition, visual; aging; neuropsychological tests

Introduction

Visual search is the ability to find target objects in complex visual scenes in everyday life [1]. Search skills are usually assessed with visual search tasks, where a target stimulus is presented among distractor stimuli on a display. The number of stimuli on the display (set size) and perceptual dimension of the stimuli are varied to manipulate the complexity of visual search tasks [2]. More complex visual search is often affected in aging, in neurodegenerative diseases, and after brain injury [3]. Studies indicate that visual search can be improved following training on visual search tasks [4] and match-3 puzzle video games [5,6]. Tile-matching match-3 (TMM3) puzzle video games require finding and matching 3 tiles of the same type on a board of tiles that differ on some dimensions. The aim of this study was to develop and initially validate a TMM3 puzzle video game that engages visual search ability in a playful and engaging way, permits control over task difficulty parameters, and enables collection of data useful for researchers.

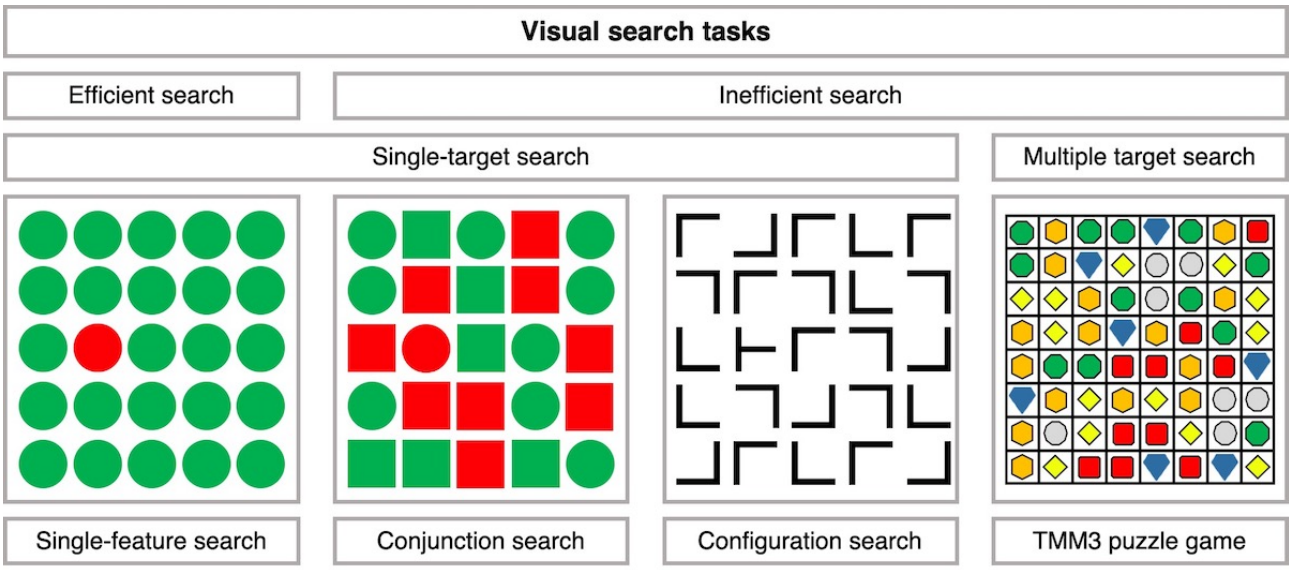
Traditional Visual Search Tasks

Visual search is required to detect a behaviorally relevant object among a set of irrelevant objects by scanning the visual environment that is important in both everyday activities (eg, finding an item on a supermarket shelf) and professional settings (eg, searching medical images for signs of abnormalities) [1,7]. Visual search is usually assessed with experimentally controlled visual search tasks that represent a suitable measure of everyday search ability [8]. In the visual search paradigm, participants are asked to detect a target stimulus defined by basic visual features (eg, color and shape) and whose presence and location are unknown, among a set of distractors (nontarget) as quickly and accurately as possible [9-11]. Overall, 2 independent variables are used to manipulate search difficulty: the total number of items on the display (set size) and the perceptual dimensions (eg, color and shape) affecting the similarity between target and distractors (target-distractor similarity) and among distractors (distractor heterogeneity) [2]. As a dependent variable, 2 measures of search performance are calculated: search time and search efficiency. Search time is measured by overall reaction time (RT), whereas search efficiency is calculated as processing time per search item. Search efficiency is derived from the slope of RTs as a function of set size (RT × set size) [2,12].

Variations and Types of Visual Search Tasks

Visual search tasks vary in search efficiency depending on the number of perceptual dimensions that affect target-distractor similarity and distractor heterogeneity [2,13]. In efficient search tasks, the target differs from distractor items by a single basic feature (Figure 1, *Single-feature Search*). Efficient search is driven by perceptual bottom-up processes and independent of the number of items in the search display (set size). As feature search depends on the similarity between the target and distractors, single-feature search becomes less efficient with increasing target-distractor similarity and distractor heterogeneity [13]. However, in everyday life, search items often consist of specific conjunctions or spatial configurations of visual features that are more difficult to detect than single features [10]. Inefficient search tasks include conjunction and configuration search. In conjunction search tasks, targets are defined by a combination of 2 features among distracting items that share only one of these 2 features (Figure 1, *Conjunction Search*). In spatial configuration search tasks, the target consists of a specific spatial arrangement of features. Although targets and distractors are composed of the same elements, they differ in their spatial configuration (Figure 1, *Configuration Search*) [14]. In inefficient search, targets differ from distractors in more than one feature dimension and need to be attended item by item. This requires attentional top-down control such that increased set size leads to prolonged search [2,15].

Figure 1. Types of visual search tasks and tile-matching match-three puzzle games. Efficient feature search where a single target (red circle) is shown among distractors (green circles) that differ in a single feature (color). Inefficient conjunction search where a single target (red circle) is presented among distractors (red squares, green circles and green squares) that share one of two target features (color or shape). In efficient configuration search (T among L) where a single target (T) is hidden among distractors (L in 4 orientations), that share the same basic features (black vertical and horizontal lines) but differ in their configuration. Controlled tile-matching match-3 puzzle game where multiple spatial configurations of three or more identical tiles must be found. These target configurations can be turned in to a line of three by swapping 2 adjacent tiles.



Visual Search in Aging, Neurodegenerative Diseases, and Brain Injury

More effortful visual search can become increasingly challenging with normal aging, neurodegenerative diseases, including Alzheimer's disease (AD) and Parkinson's disease, and after brain injury [3,16-18]. A general finding is that there is an exaggerated cost of increased set size on search time in search tasks where more than one perceptual dimension defines the target (inefficient search). Deficits in inefficient visual search were shown to deteriorate progressively from young to older adults [19-21], to mild cognitive impairment (MCI) [17,22,23], to MCI-AD converters compared with non-AD converters [24], and to patients with AD [17,23,25,26]. These findings indicate the role of visual search tasks as an indicator of age-related neuropathological changes in brain areas supporting visual search that are not usually assessed in clinical practice. Visual search is supported by frontoparietal attentional networks that are particularly vulnerable to neurodegenerative disorders [17,21]. Damage to these brain areas has also been linked with visual search deficits after traumatic brain injury [27] and stroke [28]. Although not routinely assessed in clinical practice, deficits in inefficient visual search are linked with long-term limitations in everyday activities that involve visual search [29].

Visual Search Training

Owing to the predominant role of visual search in everyday life, it is important to assess and practice visual search abilities [28]. Throughout their lifetime, humans learn combinations of visual object features (ie, conjunction and spatial relations) to optimize searching for specific objects in their everyday visual environment [30,31]. Studies have shown that younger and older adults can increase visual search ability through repeated practice on conjunction and configuration search tasks [32-34]. There is controversy whether training effects reflect low-level learning (*feature learning*) that is specific to the trained task and stimuli or high-level learning (*conjunction learning*) that is more general and transferable [35]. However, visual search training benefits were shown to be generalizable and proposed to combine both types of learning that make it important for improving visual search in everyday life [30,31,36]. On the basis of these findings, 2 new approaches to improving visual search have been taken. In the first, studies have used theory-driven computerized conjunction search tasks to both assess and improve visual search abilities. The advantage of computerized visual search tasks is that assessments and trainings can be flexibly adjusted by manipulating parameters of the task based on performance measures. Task difficulty is mainly accomplished by manipulating 2 task parameters: the total number of stimuli on the screen (set size) and the variation or heterogeneity in distractor stimuli that affect target-distractor and distractor-distractor similarity [37-39].

In a second approach, TMM3 puzzle video games (see Figure 1, *TMM3 Puzzle Game*) have been used to practice visual search ability. Recent studies showed improvements in visual search in both healthy younger and older adults after training with a TMM3 puzzle game [5,6,40,41]. This shows that puzzle games that include a search element can be used to train visual search ability. The advantage of using puzzle games is that they are highly popular, easy to learn and play, and are particularly liked by older adults [42,43]. This underlines the potential of puzzle games as a nonthreatening and enjoyable way to assess and practice visual search and cognitive function in older adults [44]. However, commercial games make it hard to control variables that affect the task difficulty, and usually, there are little means to collect data for research purposes [45].

Overall, these findings show the potential of both computerized visual search tasks and puzzle video games as means to assess and practice visual search ability. To combine the strengths of these 2 approaches, games can be modified or rewritten as *game-like tasks* or *taskified games* that can be used as valid cognitive tests and interventions while keeping all the elements of a video game [45,46]. As visual search is not routinely assessed in clinical settings, new user-friendly tools that permit assessing and practicing visual search ability in a controlled and gradable fashion are clearly needed [28,29].

Visual Search and Tile-Matching Match-3 Puzzle Games

The 2 constituent elements of TMM3 games are a puzzle board and colored shapes. The puzzle board is a rectangular or square grid, and each cell inside the grid contains a colored shape (tile). In classical TMM3 games, the goal is to eliminate as many tiles as possible in a limited time period [47]. To eliminate tiles, groups of 3 or more identical tiles must be found and aligned by exchanging the position of 2 adjacent tiles (*match*). The matched tiles are then removed, and new tiles fall in their place [48] (see Figure 1, *TMM3 puzzle game*, and Figure 2). The difficulty in TMM3 games is increased when the number of potential matches on the puzzle board decreases, making it harder to find tiles to eliminate [6].

TMM3 puzzle games combine visual search with visual pattern recognition and matching [49]. Search targets are defined by 2 features: the color and shape of the tiles and the spatial relation among them. Unlike visual search tasks, targets are always present because the goal of TMM3 games is to continuously make matches and eliminate tiles [5]. It should be noted that TMM3 puzzle games combine elements from inefficient visual search tasks (see Figure 1, *TMM3 Puzzle Game*). Similar to configuration search, the goal is to find a group or spatial arrangement of 3 identical tiles. As in conjunction search, the target is made up of a combination or conjunction of features: a visual feature (3 identical tiles) and spatial feature (target pattern configuration) [6].

In TMM3 games, there are both multiple possible targets on the puzzle board (multiple target search) and multiple types of targets (multiple category search; see Figure 2). In TMM3 puzzles, there are 16 target patterns based on 3 basic types of patterns (see Figure 2, left) [50,52–54]. Each target pattern is defined by a specific spatial relation among 3 identical tiles. Distractors in TMM3 puzzles are called false target or distractor patterns that are almost like target patterns but create no match (see Figure 3, right). Therefore, TMM3 puzzles require spatial attention and pattern recognition to discriminate targets from distractor patterns. This search is similar to inefficient visual search because spatial relations among tiles must be compared item by item until a target pattern is found [5,6,50]. A proposed search mechanism for TMM3 games is to first look for 2 adjacent tiles of the same color and shape (*find two*) and then find a neighboring third tile of the same color and shape that can be matched by making a swap (*find match*). This introduces an additional cost to visual search because of a memory search for multiple target categories [5,6,51].

Figure 2. Target pattern categories (left): The green tile can be swapped with the respective opposite red tile to make a line of 3 red tiles (match). There are 3 basic target patterns that can be matched by moving a tile diagonal from a pair of identical pieces (J-patterns), between 2 identical tiles (V-patterns) and toward a pair of tiles (i-patterns). There are 16 different types of target patterns. Distractor pattern categories (right): Distractor patterns (red tiles) are false target patterns with 2 adjacent tiles and a third tile that deviates by 1 cell from the 3 basic target patterns. Type A and C patterns are distractors of J and V target patterns, whereas type B patterns are distractors of i and J target patterns. There are a total 20 possible distractor patterns.

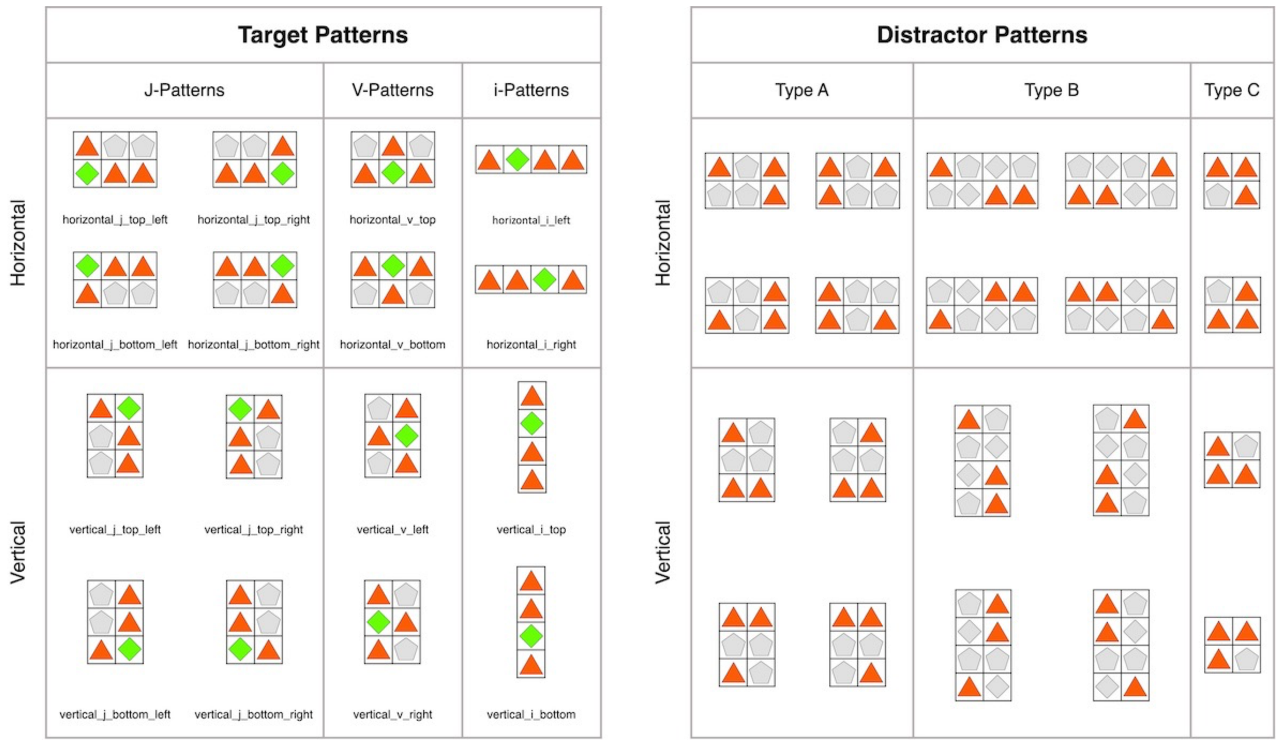
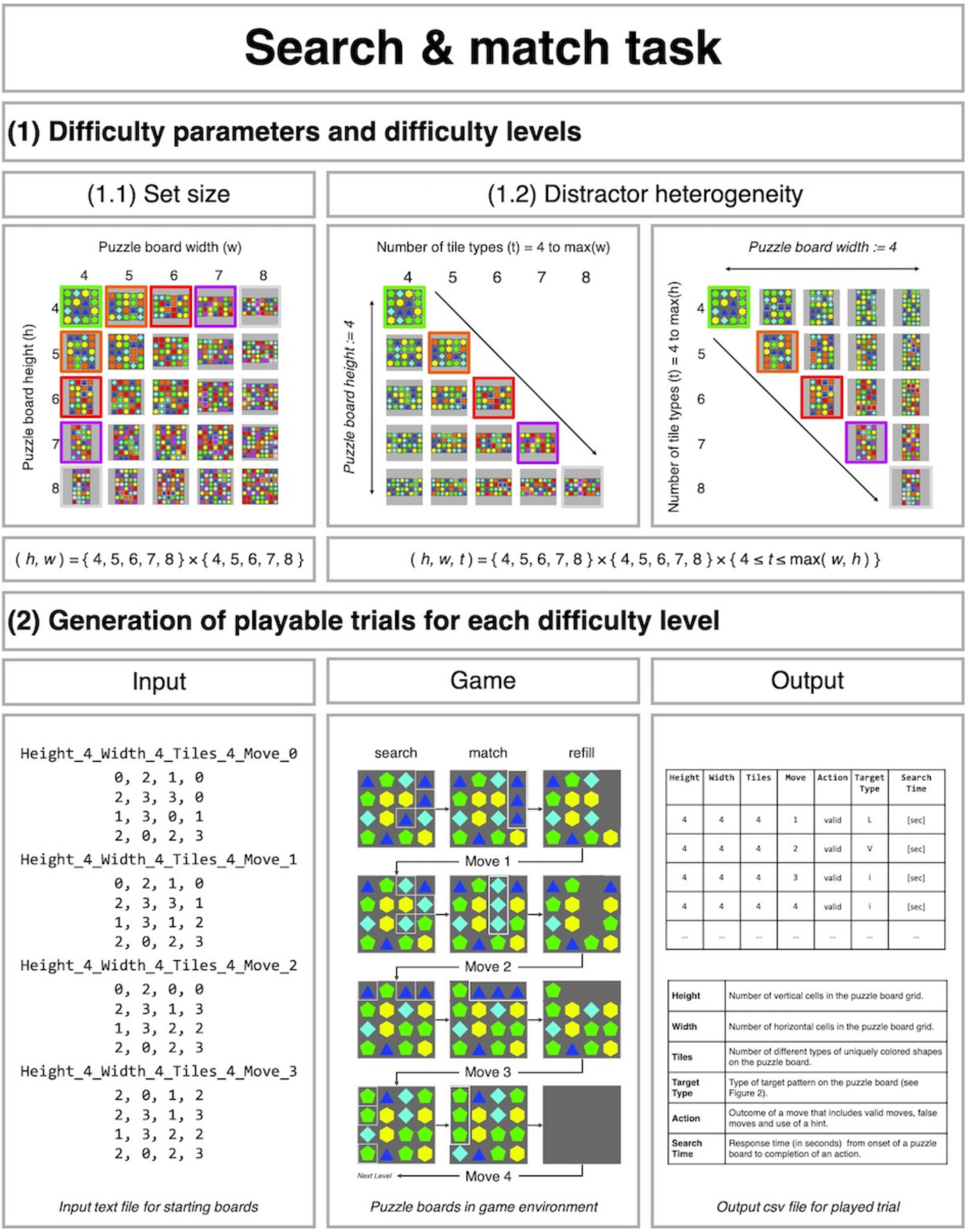


Figure 3. Difficulty parameters and development of the search & match task. (1) Difficulty parameters and difficulty levels include the set size, ie, height and width of the puzzle board, and distractor heterogeneity, ie, the number of different types of colored shapes. (1.1) Set size. Difficulty levels were first generated by creating combinations of puzzle board with widths and heights ranging from 4 to 8. (1.2) Distractor heterogeneity. For each set size, distractor heterogeneity was manipulated from 4 to the maximum value of either height or width. Examples are shown for width and height ranging from 4 to 8, with height and width set fixed at a value of 4. (2) Generation of playable trials for each difficulty level. For each difficulty level, playable trials were pregenerated as text files (Input). A trial consists of 4 consecutive puzzle boards with 1 single target pattern (Game - search). After swapping each target pattern (Game - match), the tiles are removed and replaced with new tiles (Game - refill). Trials were programmed such that after each refill there was only 1 single target pattern. Performance data was recorded at move level (Output). For further information on data collected in the Search & Match Task, see the Search & Match Task Instruction file.



Research Questions

The goal of this study was to develop and evaluate the feasibility of a TMM3 game-based visual search assessment task, called search and match task (SMT), for older adults with and without cognitive impairment. To this purpose, we combined a TMM3 puzzle video game with the visual search paradigm. The SMT controls variables that affect visual search performance and supports the collection of search time data. To control variables that affect visual search performance, difficulty levels were created by manipulating the width and height of the puzzle board (set size) and the number of different types of tiles (distractor heterogeneity). In addition, the SMT was designed as a single-target visual search task with multiple target categories. A preliminary user study in young, older, and oldest adults was conducted to preliminarily evaluate the SMT.

First (hypothesis 1), we expected that with increasing the total number of items (set size) and decreasing the number of different types of tiles (distractor heterogeneity), the task difficulty increases and vice versa. An increase in task difficulty is hypothesized to result in longer search times and higher numbers of errors (false moves) [49,52]. Second (hypothesis 2), we expected the performance on the SMT to be significantly influenced by age. On the basis of previous literature that showed age-related declines in inefficient visual search [21] and performance on a commercial TMM3 video game [5], we expected young adults to perform better than older adults and older adults to perform better than oldest adults. Third (hypothesis 3), as previous studies have suggested, we expected an association between performance on the SMT and assessments for global cognitive ability and cognitive functions required to play the SMT. These include measures of selective and divided attention [41], visual search [5,6], and spatial processing speed and pattern recognition [6,49].

Methods

Participants

In total, 28 healthy younger (20 female and 8 male) aged between 18 and 31 years (mean 21.68 years, SD 2.86), 13 healthy older adults (7 female and 6 male) aged between 64 and 79 years (mean 70.54 years, SD 3.82), and 11 oldest adults (9 female and 2 male) aged between 86 and 94 years (mean 89.27, SD 3.29) participated in this study. The younger adults were recruited from the University of Bern student participant pool, older adults were recruited from the Seniors University of Bern, and oldest adults were recruited through seniors' residences in Olten and Bern, Switzerland. The exclusion criteria for participation were (1) insufficient coordinative, motor, and perceptual ability to handle a tablet computer and (2) history of neurological or psychiatric deficits. All participants had normal or corrected-to-normal vision. All participants provided written informed consent in accordance with the latest version of the Declaration of Helsinki before participation. The cantonal ethics committees of Bern and Northwest and Central Switzerland granted the ethics approval for this study.

Neuropsychological Assessment

A total of 5 neuropsychological tasks were used to assess the concurrent criterion validity of the SMT. The trail-making test (TMT) [53] was used as a paper-and-pencil measure of attentional function. The TMT trails A measures selective attention, visual scanning, and visuomotor processing, whereas the TMT trails B measures divided attention, working memory, and inhibition [53,54]. Visual search performance was assessed with the *visual scanning* subtest from the computerized test of attentional performance (TAP) [55,56] that is used as a screening measure for visual attention [57]. In this task, participants actively scanned a 5×5 matrix and indicated whether a specific target stimulus (square with top opening) was present or not among 3 types of similar distractor stimuli (squares with openings on the left, right, or bottom). The pattern comparison task (PCT) [58] was used as a measure of spatial processing speed and pattern recognition ability. The PCT requires participants to examine a pair of 8-dot patterns shown on the left and right half of the screen and determine whether they are similar or different. The Montreal Cognitive Assessment (MoCA) [59] was administered as a measure of global cognitive ability.

Task Perception and Usability Assessment

Subjective acceptance of the SMT was assessed with the Perception of Game Training Questionnaire [60]. In this questionnaire, participants rated the extent to which they found playing the SMT *enjoyable*, *challenging*, and *frustrating* as well as their motivation while playing the mazes on a 7-point Likert scale. The 10-item system usability scale (SUS) was used to measure user experience, usability, and learnability of the SMT. The SUS provides a composite score from 0 to 100, where a higher number indicates a higher usability [61].

Characteristics and Development of the Search and Match Task

Search and Match Task Description

The SMT was designed as an experimentally controlled pattern-matching visual search task that combines advantages from both computerized visual search tasks and puzzle video games. The SMT is played on a grid-based puzzle board with a given set size (width × height) that is randomly filled with tiles from a set of uniquely colored shapes (tiles) on a gray background (see Figure 3). The SMT provides a total of 71 difficulty levels, where each level is defined by a combination of set size of the board and the number of sets of tiles.

Each difficulty level in the SMT comprises trials with 4 single-target moves. For each trial, the goal is to look for a target pattern on the puzzle board (*search*) and make a move to horizontal or vertical sequence of 3 identical tiles (*match*; see Figure 3). Moves are performed by swapping the position of 2 adjacent tiles in any of the 4 cardinal directions using the mouse or a touch-sensitive screen. A move is only valid when it creates a match. Invalid moves are not allowed, and the swapped tiles will bounce back to their initial place. After valid moves, tiles above the matched tiles fall into the now empty cells, and the resulting empty cells at the top of the board are filled with new tiles [48,52]. Therefore, to finish a difficulty-level trial, participants must make 4 consecutive matches (see Figure 3, *Game*).

In TMM3 puzzle games, there are multiple potential matches on the puzzle board at a time and search difficulty depends on the number of potential matches present on a puzzle board [6]. To study the effects of the manipulated difficulty variables in a controlled manner, the SMT was designed as a single-target search task. SMT trials are self-terminating and end as soon as the single target pattern on the puzzle board has been found and matched by making a valid move (see Figure 3, *Game*).

Search and Match Task Difficulty Parameters and Development

A full factorial analysis was used to generate multiple difficulty levels for the SMT [62,63]. Difficulty levels were generated by constructing restricted combinations of width (w) and height (h) of the puzzle board (set size), and the number of tile types (t) varied over a range from 4 to 8 [49,52].

First, all possible combinations of puzzle board widths and heights from 4 to 8 were generated: (w, h) = {4, 5, 6, 7, 8} × {4, 5, 6, 7, 8} = 25 (see Figure 3, *Set size*). The puzzle board size determines the total number of tiles on the puzzle board that must be checked to find a target pattern configuration of tiles. With increasing set size, the time to find a target pattern increases (*set size effect*) [5,6,50]. Second, for each puzzle board size, the number of tile types (t) was set from 4 to the maximal value of height or width of the puzzle board. This resulted in 95 difficulty levels: (w, h, t) = {4, 5, 6, 7, 8} × {4, 5, 6, 7, 8} × {4 ≤ t ≤ max(w, h)} (see Figure 3, *Distractor heterogeneity*). Tile types were 8 regular convex polygons (3 to 11 sides) with a unique color. The number of tile types affects the number of tiles on the puzzle board that are identical to the tiles that form the target pattern (*sharing*) and the number of tiles that do not (*grouping*). More tile types increase grouping and make it easier to find a target pattern [49,64].

Third, playable trials were generated for each of the 95 task difficulty levels using a brute force–like algorithm programmed in Python (see Multimedia Appendix 1. The SMT was specifically designed such that all puzzle boards within a trial of 4 successive matches contain exactly 1 single-target pattern. To achieve this, the algorithm first generated a 2-dimensional array (width × height), randomly filled with tiles from a range of number of tile types (tile types) for each level. The algorithm checked whether the board contained exactly 1 target pattern (see Figure 3, *Game*, *search*) and solved it and repeated checking for 1 target pattern only (see Figure 3, *Game*, *match* and *fill*). When this process could be recursively performed 4 times in a row, it was considered a playable trial (see Figure 3, *Game*). From the 95 task difficulty levels, all levels with a minimum of 47 playable trials were selected and sorted by set size. This step yielded playable trials for 71 of the 95 prespecified difficulty levels (see Multimedia Appendix 1). The 71 generated difficulty levels were then divided into 2 parallel versions with 40 difficulty levels, each based on set size (see Multimedia Appendix 1). Both parallel versions contained all available square (w=h) difficulty levels, whereas the rectangular (w ≠ h) difficulty levels were assigned to the 2 versions in a parallelized fashion. This way, the number of levels could be reduced, while providing all available set sizes (w × h).

Procedure

First, participants were informed about the procedures of the user study and written consent was obtained. Second, in the cognitive assessment session, the MoCA and the TMT trail A and trail B (completed by all participants) were administered in paper-pencil format, whereas the computerized visual scanning TAP task and the PCT (completed only by young and older adults) were presented on a computer. Third, in the difficulty evaluation session, participants played the pregenerated SMT difficulty levels. The SMT visual search task was played on a tablet computer (Apple 12.9” iPad Pro, Apple Inc) with a version of the SMT programmed in Unity 3D (Unity Technologies). To ensure that participants understood how to play the SMT, they were first provided instructions (see Instructions and Task in the Multimedia Appendix 2 and) and a practice block. The experimenter read the instructions to the participants and showed them the 3 basic target patterns to look out for. In addition, the participants were told that there was only 1 target pattern to match at a time. After that, the participants played a practice block with 3 incremental difficulty levels (w, h, p) = {(4, 4, 4), (5, 5, 5), (6, 6, 6). Here, they were shown how to use the *hint* button that highlights the target pattern when they could not find it and encouraged to use it when needed. In the test block, participants completed the SMT difficulty levels. The younger and older adults completed the full set of difficulty levels (long version, 40 levels) of the SMT. On the basis of previous experience with oldest adults, we chose to use a shortened version of difficulty levels with the lower third of difficulty levels (short version, 12 levels; see Multimedia Appendix 1 and). This was mainly for reasons of time and not to overburden the participants. The 2 parallel versions of the task were counterbalanced across participants. For each difficulty level, a trial was randomly drawn from the respective difficulty level folder of pregenerated trials. Each trial for every difficulty level consisted of 4 consecutive matches (Figure 3, *Game*). After completing each level, participants were asked to rate the difficulty of the played trial on a 10-point Likert scale ranging from 1 (*very easy*) to 10 (*very difficult*). The difficulty levels in the test block were presented in random order to avoid learning effects that might occur when presented in incremental order [65]. After completing all levels, the participants evaluated the usability and their experience with the SMT by filling in the SUS and the Perception of Game Training Questionnaire.

Statistical Analysis

A summary file with entries for each played move on the SMT was stored. Each move entry included the trial number, height and width of the puzzle board, and the number of unique tile types. Furthermore, the move number, time to make the move (search time), accuracy (correct or false move), and whether a hint was used to make a correct move were recorded. To calculate the search time for each puzzle board, all false moves leading up to a correct move were summed up. Trials with outliers in search time (search times greater or less than 1.5 × interquartile range for each age group) were removed from analysis. The following time-based performance indicators were calculated: overall solving time (min), average target search time (sec), average processing time per item (sec), and search slope (sec/item).

Processing time per item was calculated by dividing search time by the number of items in the display.

Search slope was calculated by means of a general linear model (GLM), assuming gamma distribution because of nonnormal search time data. The model included search time as a response variable and an interaction term for set size and age group as a predictor variable. Error-based performance measures included the number of false moves and the number of used hints. For all further analyses, trials where a hint was used were excluded.

First, age-group differences in demographic variables, neuropsychological test measures, and SMT puzzle game performance measures were analyzed. Visual inspection of histograms, quantile-quantile plots, and Shapiro-Wilk and Anderson-Darling (for the long puzzle version data) tests revealed that these variables were nonnormally distributed. Statistical differences between the 3 age groups were performed in R Version 1.1.463 [66] using the nonparametric Kruskal-Wallis test, with subsequent pairwise Wilcoxon rank sum tests (using Bonferroni correction) for post hoc intergroup comparisons. An alpha value of .05 was used to determine significance. Post hoc comparisons between search slopes by age group were performed using Tukey's honest significance test implemented in the lstrends function from the lsmeans package [67] for R.

For all analyses below, only search times for trials without hints were analyzed.

Second, the effect of the 2 manipulated task parameters (as per hypothesis 1) and age (as per hypothesis 2) on search time (dependent variable) was tested. As the search time data were positively skewed (short version dataset: skewness=0.65, SD 1.11; long version dataset: skewness=0.56, SD 0.61), we performed a general linear mixed-effect model (GLMEM) analysis using the lme4 package [68]. To approximate the distribution of the search time data, we assumed a gamma distribution with inverse link function (see the study by Lo and Andrew [69] for recent guidelines). In addition, 2 GLMEMs assuming gamma distribution (inverse link function) with search time as outcome; set size, the number of unique tile types (within-subjects factors), and age (between-subjects factor) as fixed effects; and a random intercept per subject as a random effect were fitted. We performed this analysis separately on the short puzzle difficulty version (12 levels), which was played by all age groups, and on the long or full puzzle difficulty version (40 levels, including the 12 levels from the short version), which was played by the young and older adults.

Third, external validity was examined through correlation analyses (using the Spearman rank correlation coefficients) between the geometric mean search time and the performance on cognitive tests with measures of selective (TMT A completion time) and divided (TMT B completion time), visuospatial processing speed and pattern recognition (mean overall response time), and visual search (mean response time for target present trials). Separate partial correlation analyses (again using the Spearman rank correlation coefficients), controlling for the effect of participant age, were performed. Both analyses were performed separately for the short (all age groups) and long (young and older adults) difficulty-level versions using the sjstats [70] and ppcor package [71].

Results

Results for Demographic Variables and Neuropsychological Tests

Demographic variables and neurocognitive measures by age group are shown in Table 1. Regarding demographic characteristics, the 3 age groups differed significantly on age at test (χ^2_2=42; *P*<.001) and years of education (χ^2_2=16; *P*<.001). The oldest adults (mean 89.27) were significantly older than the older adults (mean 70.54; *P*<.001) and young adults (mean 21.68; *P*<.001), and the older adults were significantly older than the young adults (*P*<.01). Duration of education was significantly lower in the oldest adults (mean 11.73) group compared with the older (mean 15.92; *P*<.01) and young (mean 14.47; *P*<.01) adults, but it was not different between older and young adults (*P*=.53).

Concerning neuropsychological test measures, global cognitive ability was significantly different between the 3 groups (χ^2_2=14.5; *P*<.001) and significantly lower in the oldest adults (mean 24.27) compared with the young adults (mean 28.32; *P*<.001). In terms of performance on attentional tasks, there were significant effects of age group in selective attention time (χ^2_2=15.2; *P*<.001) but not errors (χ^2_2=3.3; *P*=.19) and in divided attention time (χ^2_2=26.6; *P*<.001) as well as errors (χ^2_2=8.9; *P*<.01). In selective attention, the younger adults (mean 26.44) were significantly faster than older adults (mean 36.15; *P*=.027) and oldest adults (mean 58.18; *P*<.001), and the older adults were significantly faster than the oldest adults (*P*<.01). In divided attention, younger adults (mean 50.78) were significantly faster than older adults (mean 107.69; *P*<.001) and oldest adults (mean 155.60; *P*<.001). Younger adults (mean 0.50) made significantly fewer errors than older (mean 2.85; *P*=.04) and oldest adults (mean 1.55; *P*=.02).

In the computerized visual search and visuospatial processing task that was completed only by the younger and old adult group, there was a significant difference between younger and older adults in visual search (trials with target present: mean 2.02 vs 3.85; χ^2_1=21.1; *P*<.001 and trials with targets absent: mean 3.62 vs mean 6.96; χ^2_1=19.6; *P*<.001) and visuospatial processing (mean 1.69 vs mean 3.85; χ^2_1=22.5; *P*<.001).

Table 1. Means and SDs for the demographic variables and neuropsychological test measures by age group.

Variables	Young adults aged 18-35 years (n=28)	Older adults aged 65-85 years (n=13)	Oldest adults aged 85+ years (n=11)	*P* value	Group comparison
Demographic variables					
Age (years), mean (SD)	21.68 (2.86)	70.54 (3.82)	89.27 (3.29)	<.001[a]	Young < older < oldest
Gender (female/male)	20/8	7/6	9/2	—[b]	—
Education (years), mean (SD)	14.47 (1.94)	15.92 (2.42)	11.73 (1.49)	<.001[a]	Young, older < oldest
Neuropsychological tasks, mean (SD)					
Montreal cognitive assessment[c] total	28.32 (1.74)	27.15 (3.08)	24.27 (3.04)	<.001[a]	Young > oldest
TMT-A[d] time (seconds)	26.44 (9.38)	36.15 (7.69)	58.18 (15.54)	<.001[a]	Young < older < oldest
TMT-A errors, mean (SD)	0.00 (0.00)	0.08 (0.28)	0.18 (0.40)	.19[e]	NS[f]
TMT-B[g] time (seconds)	50.78 (19.30)	107.69 (43.21)	155.60 (49.72)	<.001[a]	Young < older, oldest
TMT-B errors	0.50 (1.89)	2.85 (4.41)	1.55 (1.51)	.01[h]	Young < older, oldest
Visual scanning TAP[i] (seconds)	2.28 (0.56)	4.06 (0.64)	—	<.001[a]	Young < older
Pattern comparison overall (sec)	1.63 (0.29)	2.97 (0.54)	—	<.001[a]	Young < older
Task perception, average difficulty rating, and usability, mean (SD)					
Enjoyable[j]	5.32 (1.09)	5.92 (0.86)	6.10 (1.60)	.12[e]	NS
Challenging[j]	4.00 (1.68)	5.62 (1.04)	5.50 (0.97)	.01[h]	Young < older
Frustrating[j]	2.11 (1.45)	2.54 (1.61)	2.30 (2.21)	.74[e]	NS
Motivating[j]	5.96 (1.07)	6.31 (0.48)	6.50 (0.97)	.25[e]	NS
Average difficulty rating[k] (short)	2.69 (1.62)	3.34 (1.48)	3.43 (2.24)	<.001[a]	Young < older, oldest
Average difficulty rating[k] (long)	2.82 (1.68)	3.43 (1.69)	—	<.001[a]	Young < older
System Usability Scale score[l]	88.61 (7.28)	79.09 (15.50)	68.25 (18.78)	<.01[h]	Young > oldest

[a]Significant at the .001 level.
[b]Not applicable.
[c]Score: 1-30.
[d]TMT A: trail-making test, trail A.
[e]Significant at the .05 level.
[f]NS: not significant.
[g]TMT B: trail-making test, trail B.
[h]Significant at the .01 level.
[i]Visual scanning: subtest visual scanning from the computerized test of attentional performance.
[j]Perception of Game Training Questionnaire (7-point Likert scale).
[k]Single ease question (range: 1, *very easy* to 10, *very difficult*).
[l]Score: 0-100.

Results for Perception, Average Difficulty Ratings, and Usability of the Search and Match Task

In terms of perception of the SMT as a game-based training, there were significant differences between the 3 age groups regarding ratings of challengingness (χ^2_2=10.2; *P*<.001). However, there were no significant differences in terms of enjoyment, frustration, and motivation while playing the SMT task. On the whole, young adults (mean 4.00) perceived the SMT as significantly less challenging than older adults (mean 5.62; *P*=.02).

Regarding average difficulty rating based on ratings for each difficulty level, there were significant age group differences in average difficulty ratings for both the short version played by the young, older, and oldest adults (χ^2_2=266.6; *P*<.001) and the long version (χ^2_2=479.4; *P*<.001) played by the young and older adults. Average difficulty ratings for all played levels in the short version revealed that younger adults rated these difficulty levels as significantly less difficult (mean 2.69) than both the older (mean 3.34; *P*<.001) and oldest adults (mean 3.43; *P*<.001). Average difficulty ratings for all levels in the long version further showed that the young adults (mean 2.82) gave significantly lower difficulty ratings than the older adults (mean 3.43; *P*<.001).

Overall system usability ratings for the SMT indicated a significant effect of age group (χ^2_2=10.4 *P*<.01). Oldest adults (mean 68.25) ranked the usability significantly lower than young adults (mean 88.61; *P*=.007). Individual usability ratings ranged from 72.50 (*good*) to 97.50 (*excellent*) in young, from 52.50 (*okay*) to 100 (*excellent*) in older, and from 32.50 (*unacceptable*) to 95.00 (*excellent*) in oldest adults [72].

Performance on the Search and Match Task

For the short puzzle version, as shown in Table 2, time-based performance measures revealed significant age-group differences in overall completion time (χ^2_2=337.6; *P*<.001), average target search time for all trials (χ^2_2=374.1; *P*<.001), and trials without hints (χ^2_2=330.3; *P*<.001). Post hoc analyses for task completion time for the short difficulty level version showed that young adults (mean 5.34) were significantly faster compared with both older adults (mean 15.26; *P*<.001) and oldest adults (mean 21.99; *P*<.001). In addition, older adults were significantly faster than the oldest adults (*P*<.001).

Table 2. Means and SDs for search and match task performance measures by age group.

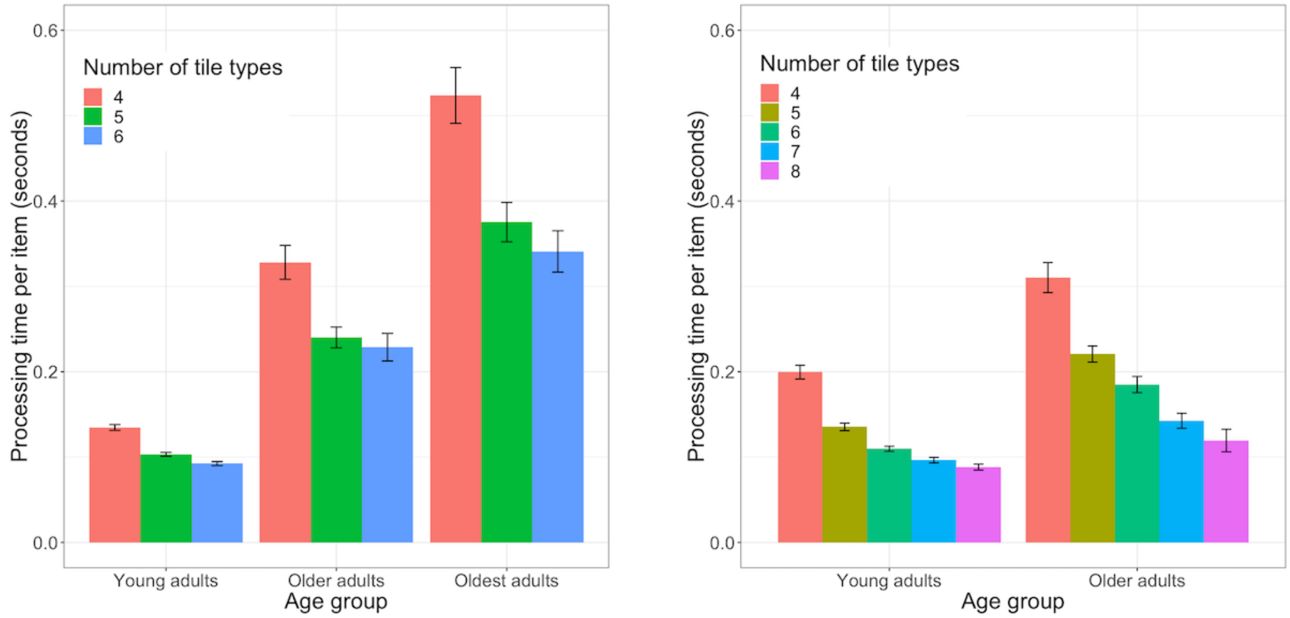
Variables	Young adults aged 18-35 years (n=28)	Older adults aged 65-85 years (n=13)	Oldest adults aged 85+ years (n=11)	*P* value	Group comparison
Short puzzle version (w, h, t) = {4, 5, 6} × {4, 5, 6} × {4 ≤ t ≤ max(w, h)} = 12 levels					
Task completion time (min), mean (SD)	5.34 (1.91)	15.26 (6.23)	21.99 (9.02)	<.001[a]	Young < older < oldest
Average search time (seconds) with hints, mean (SD)	2.75 (1.58)	4.31 (3.86)	8.39 (7.99)	<.001[a]	Young < older < oldest
Average search time (seconds) without hints, mean (SD)	2.74 (1.57)	4.34 (3.91)	8.43 (8.05)	<.001[a]	Young < older < oldest
Search slope (sec/item)	1.37	.26	.49	.63[b]	Young = older = oldest
Processing time per item (sec), mean (SD)	0.11 (0.07)	0.27 (0.21)	0.42 (0.36)	<.001[a]	Young < older, oldest
Total number of false moves, mean (SD)	0.02 (0.14)	0.31 (0.46)	0.28 (0.45)	<.001[a]	Young < older, oldest
Total number of used hints, mean (SD)	0.15 (0.42)	0.35 (0.70)	0.61 (0.76)	<.001[a]	Young < older < oldest
Long puzzle version (w, h, t) = {4, 5, 6, 7, 8} × {4, 5, 6, 7, 8} × {4 ≤ t ≤ max(w, h)} = 40 Levels					
Task completion time, mean (SD)	17.75 (5.58)	35.94 (24.96)	—[c]	<.001[a]	Young < older
Average search time (seconds) with hints, mean (SD)	4.16 (5.19)	4.81 (4.30)	—	<.001[a]	Young < older
Average search time (seconds) without hints, mean (SD)	4.14 (5.21)	4.82 (4.34)	—	<.001[a]	Young < older
Search slope (sec/item)	1.69	−.56	—	<.001[a]	Young > older
Processing time per item (sec), mean (SD)	0.12 (0.16)	0.21 (0.18)	—	<.001[a]	Young < older
Total number of false moves, mean (SD)	0.02 (0.13)	0.28 (0.45)	—	<.001[a]	Young < older
Total number of used hints, mean (SD)	0.14 (0.42)	0.49 (0.88)	—	<.001[a]	Young < older

[a]Significant at the .001 level.

[b]Not significant.

[c]Indicates long puzzle difficulty version not completed by oldest adults.

Figure 4. Average processing time per item (tile) for the short (left) and long (right) puzzle difficulty level version by age group and number of tile types.



Regarding average search time (for both trials where a hint was used and trials without hints), oldest adults (mean 8.39; mean 8.43) were significantly slower than both older adults (mean 4.32; mean 4.34; *P*<.001) and young adults (mean 2.75; mean 2.74, *P*<.001), and older adults were significantly slower than young adults (*P*<.001), respectively. In the analysis of search slopes for the short version puzzle difficulty levels, GLM analysis showed a significant effect of age group (χ^2_2=2113.1; *P*<.001) on search time. The effect of set size (χ^2_2=2.3; *P*=.13) and the interaction between set size and age group (χ^2_2=0.9; *P*=.63) were not significant. Post hoc analysis revealed that search slopes were not significantly different between young and older adults (*P*=.62), young and oldest adults (*P*=.69), and older and oldest adults (*P*=.96). Average processing time per item across different number of tile types revealed was significantly different between age groups (χ^2_2=705.7; *P*<.001). Younger adults (mean 0.15) took significantly less processing time per item than both older (mean 0.35; *P*<.001) and oldest (mean 0.61; *P*<.001) adults, and older than oldest adults (*P*<.001). Figure 4 (left) shows processing times per item by age group and by the number of tile types to illustrate the additional effect of distractor heterogeneity.

For the accuracy-based performance measures, there was a significant effect of age group on the total number of false (invalid) moves (χ^2_2=680.9; *P*<.001) and the total number of used hints (χ^2_2=563.8; *P*<.001). Compared with the young adults (mean 0.02), the older (mean 0.35; *P*<.001) and oldest adults (mean 0.28; *P*<.001) made significantly more false moves. The oldest adults (mean 0.61) used significantly more hints than both the older (mean 0.35; *P*<.001) and young adults (mean 0.15; *P*<.001), and the older adults significantly more than the younger adults (*P*<.001).

For the long puzzle version played by the young and older adults (Table 2), there was a significant effect of age group in overall task completion time (χ^2_2=698.9; *P*<.001), with older adults taking significantly longer than young adults to complete the long difficulty level version. For both trials with (χ^2_2=374.1; *P*<.001) and without hints (χ^2_2=81.7; *P*<.001), average search time was significantly slower in older than in young adults. The GLM analysis for search slopes revealed a significant interaction between age group and set size (χ^2_2=14.30; *P*<.001) and significant effects of set size (χ^2_2=21.2; *P*<.001) and age group (χ^2_2=123.6; *P*<.001) on search time. Post hoc comparisons showed that search slopes were significantly different between young and older adults (*P*<.001). In addition, age significantly influenced average processing time per item (χ^2_2=383.6; *P*<.001) and older adults (mean 0.21) were significantly slower than younger adults (mean 0.12; *P*<.001). Figure 4 (right) shows processing times per item by age group and separately for the different number of tile types to illustrate the effect of distractor heterogeneity. In terms of accuracy-based performance measures, older adults made significantly more false moves (χ^2_2=1770.9; *P*<.001) and used significantly more hints (χ^2_2=664; *P*<.001)) than young adults.

Results for Generalized Linear Mixed-Effect Models

For the short version, as shown in Table 3, the GLMEM revealed a significant positive effect of set size ($F_{1,2760}$=2.18; *P*=.01; Cohen f=.026), a significant negative effect of the number of tile types ($F_{1,2760}$=8.17; *P*=.01; Cohen f=.05) and a significant positive effect of age ($F_{1,2760}$=408.3; *P*<.001; Cohen f=.35) on target search time.

Table 3. General linear mixed-effect model results for the effect of set size, number of tile types (distractor heterogeneity), and age on search time on the short puzzle version with all age groups (young, old, and oldest adults) and the long puzzle version (young and older adults).

Variables	Short difficulty levels version, search time (seconds)			Long difficulty levels version, search time (seconds)		
	Estimates	CI	*P* value	Estimates	CI	*P* value
Set size	1.29	0.34 to 2.24	.01[a]	2.24	1.84 to 2.64	<.001[b]
Number of tile types	−8.87	−15.61 to −2.13	.01[a]	−16.46	−20.50 to −12.42	<.001[b]
Participant age	3.82	3.37 to 4.27	<.001[b]	1.90	1.19 to 2.61	<.001[a]

[a]Significant at the .01 level.

[b]Significant at the .001 level.

For the long version, the GLMEM analysis revealed a significant positive effect of set size ($F_{1,7569}$=34.70; *P*<.001; Cohen f=.08), a significant negative effect of the number of tile types ($F_{1,7569}$=35.86; *P*<.001; Cohen f=.081), and a significant positive effect of age ($F_{1,7569}$=14.12; *P*<.001; Cohen f=.051) on target search time.

Results for External Validity Testing

To assess external validity, time-based performance on the SMT (geometric mean search time) was compared with performance on standard neuropsychological tests. External validity testing results are reported separately for the short and long difficulty levels version in Table 4.

For the short puzzle difficulty level version, Spearman correlation analyses showed significant positive associations between geometric mean search time and TMT A completion time (*r*=.724; *P*<.001) and TMT B completion time (*r*=.755; *P*<.001). Furthermore, there was a significant negative correlation between geometric mean search time and the MoCA score (*r*=−.453; *P*=.01). To further evaluate the contribution of age on the neuropsychological tests, partial correlations of geometric mean search time with the neuropsychological test measures controlling for age were assessed. The partial correlation of both TMT A (*r*=.374; *P*=.02) and TMT B (*r*=.342; *P*=.03) completion time with geometric mean search time remained significant when controlling for age. However, the partial correlation between MoCA (controlling for age) and geometric mean search time was not significant (*r*=−.178; *P*=.27).

For the long puzzle level version, geometric mean search time was significantly positively associated with TMT A (*r*=.546; *P*<.001) and TMT B (*r*=.573; *P*=.001) completion time, average target search time on a computerized visual search task (*r*=.430; *P*=.007) and average response time on a visuospatial processing and pattern recognition task (*r*=.543; *P*<.001). However, the association with MoCA scores (*r*=−.223; *P*=.16) was not significant. When controlling for age, only the positive relationship with TMT A (*r*=.49; *P*=.008) and TMT B (*r*=.43; *P*=.02) completion time remained significant. However, the partial correlation between SMT performance and visual search task performance (*r*=.064; *P*=.75) as well as performance on the visuospatial processing and pattern recognition task (*r*=.038; *P*=.85) was not significant anymore.

Table 4. Correlations and partial correlations (controlling for age) between search and match task performance (geometric mean search time) and performance on neuropsychological tests for the short and long puzzle versions.

Test measure	Short difficulty level version, geometric mean search time				Long difficulty level version, geometric mean search time			
	Simple correlation		Adjusted for age		Simple correlation		Adjusted for age	
	ρ	*P*	ρ	*P*	ρ	*P*	ρ	*P*
Trail-making test A completion time	.724	<.001[a]	.373	.02[b]	0.546	.01[c]	.49	.01[c]
Trail-making test B completion time	.755	<.001[a]	.342	.03[b]	0.573	.01[c]	.43	.02[b]
Montreal cognitive assessment	−.435	.01[c]	−.178	.27[d]	−.223	.162[d]	−.316	0.1[d]
Pattern Comparison	—[e]	—	—	—	.543	<.001[a]	.064	.75[d]
Visual Scanning	—	—	—	—	0.43	.01[c]	.038	.2[d]

[a]Significant at the .001 level.

[b]Significant at the .05 level.

[c]Significant at the .01 level.

[d]Not significant.

[e]Ttests not completed by the oldest adults and therefore not used in correlational analysis across all age groups.

Discussion

Principal Findings

The aim of this study was to develop and examine the initial validity of an experimentally controlled version of a popular TMM3 puzzle video game—the SMT. The SMT was specifically designed as a single-target, pattern-matching visual search task with multiple levels of difficulty. The preliminary results of this study show that an entertaining commercial puzzle video game can be adapted as a visual search task that allows control over task difficulty and collection of relevant performance data.

First, preliminary results of our user study indicate that the SMT difficulty can be manipulated with 2 task parameters. Performance on the task (search time) increased with the total number of search items in the display (set size) and decreased with the number of types of tiles (distractor heterogeneity). Second, we found a significant effect of age group on search time in the SMT. Young adults had faster search times than older and oldest adults, and older adults were faster than oldest adults. Third, the SMT showed significant relationships with cognitive tests that measure general cognitive ability, selective and divided attention, and visuospatial and pattern recognition ability.

Comparison With Previous Work

Unlike newer approaches that have introduced game-like elements to visual search tasks (*task gamification*), this study combines an entertaining and enjoyable puzzle video game with features of the visual search paradigm (*game taskification*). This approach achieves 3 goals. First, we make use of the motivational properties of a highly popular recreational puzzle game that engages visual search and other cognitive abilities and is user-friendly and enjoyable for older adults. Second, it allows researchers to control and systematically vary variables that affect the task difficulty. This allows to accommodate players with different levels of cognitive ability, which is particularly important for diagnostic and interventional purposes. Third, this supports collecting relevant performance data otherwise not available from computer games.

First, mixed-model analyses from the initial validation study indicate that the SMT meets the 2 criteria used to manipulate the difficulty levels of the task. The results revealed significant positive effects of the total number of search items in the display (set size) and a significant negative effect of the number of different types of distractors (distractor heterogeneity) on the performance in the SMT (search time).

The significant positive effect of set size on target search time is consistent with findings from previous visual search literature. Set size effects are well documented and determine task difficulty in feature conjunction and configuration search tasks. More recently, set size manipulations have been successfully used in computerized visual search training tasks to adapt the difficulty of the task [28,39,73]. Similarly, we conclude that finding a target pattern in the TMM3 game–based SMT becomes more difficult with increasing set size as it requires searching a larger puzzle board area with more tiles that may potentially constitute a target pattern. The significant negative effect of distractor heterogeneity on target search time suggests that finding a target pattern (*match*) is less difficult when there are more different types of tiles on the puzzle board. This indicates a facilitatory effect of the heterogeneity of the puzzle board. When the number of tiles and heterogeneity increase, there are fewer tiles that share the visual feature with the target pattern (*grouping effect*) and pattern detection is easier. Conversely, when heterogeneity decreases, more tiles are identical to the tiles that constitute a target pattern (*sharing effect*). This might have a distracting effect and pattern detection is harder [49,64].

Second, the age effect seen in our study agrees with similar findings from conjunction and spatial configuration search literature that reported age-related declines in search performance that start in middle-aged adults and progress throughout older age [21,74]. Moreover, we validate a recent study that found a significant association between age and game-based high scores (ie, number of matched tiles) on a classical TMM3 puzzle game in a similar sample of young and older adults [5]. Instead of match-based high scores, our study provided search time– and error-based measures otherwise not available from commercial games. This finding reflects the interindividual variability and differences in visual search ability seen in normal aging but also in neurodegenerative diseases and after brain injury. This variability should be addressed with tools providing multiple difficulty levels, in particular for diagnostic and interventional purposes [17,28]. As a puzzle game–based visual search task, the SMT provides a range of difficulty levels aimed to accommodate the needs for clinical settings that are usually not met by commercial puzzle video games.

Third, external validity testing provides preliminary support for a TMM3 puzzle game–based visual search task to engage perceptual and cognitive abilities that are subject to age-associated decline. Our results revealed significant associations between performance on the SMT (search time) with measures of selective and divided visual attention, visuospatial processing and pattern recognition, and visual search.

These findings are in agreement with findings from 2 earlier studies that reported significant relationships between performance on a TMM3 puzzle game and simple visual search tasks in younger and older adults [5] and measures of selective and divided attention in older adults [41,75]. Moreover, this relates the SMT to perceptual inhibition skills required to suppress distracting tiles when searching for a target pattern and working memory skills needed to keep track of multiple separate groups of tiles [6,73]. For both the young and older adults, we further found an association with visuospatial processing speed and pattern recognition. This underlines that the SMT requires higher-level pattern recognition ability to find the target patterns that can be matched [6,49].

Partial correlation analyses controlling for age revealed moderate significant positive correlations of performance on the SMT (both short and long version difficulty levels) with TMT A and TMT B completion time. This suggests that our TMM3 game–based task involves psychomotor processing, selective and divided visual attention, and executive components such as inhibition and updating. However, the correlations between game performance and global cognitive ability as well as computerized assessments of visual search and pattern comparison disappeared when age was controlled. A likely explanation for these findings could be found in the design of this study. The oldest adults only played the short difficulty level version that might not have been sufficient to capture changes in search efficiency as shown in the absence of an age difference in search slopes. In addition, the younger and older adults who played the long difficulty level version and performed the computerized visual search and PCT did not differ in global cognitive ability.

Finally, our results on perception and usability of the SMT replicate 2 previous studies [42,43] that showed that TMM3 puzzle games are enjoyable, motivating, user-friendly, and easy to use. As another study showed, older adults also value the perceived benefits (ie, improving cognition and stress relief) of this game [43]. However, we found that the perception of overall challengingness and level-based difficulty ratings differed between age groups. On the one hand, this might simply reflect the age-related differences in time- and error-based performance measures on the SMT. On the other hand, it might be that it was harder for older adults to learn to play the game.

Limitations

This preliminary study included a small sample size of individuals with age-appropriate cognitive ability. Therefore, more research is needed using larger samples across a wider range of age groups and cognitive abilities. Although convergent validity indicates promising relationships with measures of attention, visuospatial, and executive function, a wider range of cognitive tasks is required to more comprehensively establish the relationship between the puzzle game–based visual search task and neuropsychological tests of cognitive functions. This would help better determine the validity of puzzle game–based tasks for assessing and monitoring age-related declines in visual search and other cognitive abilities.

Furthermore, this initial validation study is cross-sectional, and participants played age-appropriate sets of difficulty levels for the game-based visual search task only once. Therefore, older and oldest adults played the game for the first time and this task novelty might have affected task performance. This is reflected by the fact that the game was perceived as more challenging and difficult by the older and oldest adults. A reason for this is that participants need to memorize the basic target pattern configurations that must be searched and matched in order to play the game [76]. It is likely that older adults not only were slower in finding the target per se but also found it harder to memorize and learn the actual different target patterns. In addition, the SMT was designed as a single-target visual search task. Compared with commercial TMM3 puzzle games with multiple targets, this might additionally make the SMT harder to play. In future studies, this should be addressed by looking at learning effects when playing the SMT over longer time periods.

Our results indicate that the SMT difficulty can be successfully varied by manipulating set size and distractor heterogeneity. However, there are potential factors that we did not control that might additionally influence the difficulty of the SMT. First, unfortunately, we were not able to generate playable trials for the full range of the 95 difficulty levels specified in the full-factorial analysis (see Multimedia Appendix 1). These missing levels particularly concern levels with larger set sizes and small number of types of tiles: for example, (w, h, t) = 8, 8, 4. Owing to the low number of tile types, there were too many target patterns per puzzle board, such that is was impossible to generate 4 consecutive matches with only 1 target pattern per puzzle board. This of course limits the fine-grained range of difficulty levels we intended to provide. Second, the type and location of the target in the SMT was not controlled and left to random. Thus, we could not control the potential effects of different target types and target location as well as the effect of distance between targets across consecutive matches. Finally, this study used a restricted range of difficulty levels for reasons of time and burden. However, the algorithm used to generate the SMT difficulty levels in this study allows to generate more exhaustive levels for future studies.

Conclusions

Taken together, this study shows that an everyday puzzle game–based task can be experimentally controlled and provides relevant performance data to assess visual search and cognitive abilities in normal aging. The game-based SMT is enjoyable, motivating, and user-friendly for older adults.

Future studies might also use the potential of such *taskified* or *hybrid* games to assess whether they can reliably assess cognitive abilities and impairment in older adults and patients with dementia or brain injury. This would help better determine the validity of puzzle game–based tasks for assessing and monitoring age-related declines in visual search and other cognitive abilities. Finally, the potential of an intervention using the available difficulty levels to practice visual search and cognitive ability in an enjoyable and adaptive way could be further explored.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Lists of generated puzzle levels as referenced in manuscript text.

[DOCX File, 55KB - games_v7i2e13620_app1.docx]

Multimedia Appendix 2

Instructions for the search and match mask Windows.

[DOCX File, 5MB - games_v7i2e13620_app2.docx]

Multimedia Appendix 3

Instructions for the search and match task Mac OS.

[DOCX File, 79MB - games_v7i2e13620_app3.docx]

Multimedia Appendix 4

Search and match task for Windows.

[ZIP File (Zip Archive), 4MB - games_v7i2e13620_app4.zip]

Multimedia Appendix 5

Search and match task for Mac OS.

[ZIP File (Zip Archive), 5MB - games_v7i2e13620_app5.zip]

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Abbreviations

AD: Alzheimer's disease
GLM: general linear model
GLMEM: general linear mixed-effect model
MCI: mild cognitive impairment
MoCA: Montreal cognitive assessment
PCT: pattern comparison task
RT: reaction time
SMT: search and match task
SUS: System Usability Scale
TAP: test of attentional performance
TMM3: tile-matching match-3
TMT: trail-making test

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Original Paper

What Can Be Achieved With Motivation-Based Teaching of Medical Students? A Monocentric Retrospective Audit of Retention Among Highly Motivated Graduates Who Underwent the Learning-by-Doing Concept in Anesthesiology and Intensive Care Medicine

Martina Klincova[1*], MD; Hana Harazim[1*], MD; Daniel Schwarz[2], MSc, PhD; Martina Kosinova[1], MD, PhD; Olga Smekalova[3], MD; Petr Stourac[1], MD, PhD

[1]Department of Pediatric Anesthesiology and Intensive Care Medicine, University Hospital Brno, Faculty of Medicine, Masaryk University, Brno, Czech Republic

[2]Institute of Biostatistics and Analyses, Faculty of Medicine, Masaryk University, Brno, Czech Republic

[3]Department of Anesthesiology and Intensive Care Medicine, University Hospital Pilsen, Faculty of Medicine in Pilsen, Charles University, Pilsen, Czech Republic

[*]these authors contributed equally

Corresponding Author:
Petr Stourac, MD, PhD
Department of Pediatric Anesthesiology and Intensive Care Medicine
University Hospital Brno
Faculty of Medicine, Masaryk University
Jihlavska 20
Brno, 62500
Czech Republic
Phone: 420 602745841
Email: petr.stourac@gmail.com

Abstract

Background: Medical education, in general, is undergoing a significant shift from traditional methods. It becomes very difficult to discover effective teaching methods within the limited possibilities in patient hands-on education, especially as seen in anesthesiology and intensive care medicine (AIM) teaching. Motivation-based teaching is very popular in all other aspects of education, but it has received scant attention in medical education literature, even though it can make a real difference for both students and physicians.

Objective: The primary aim of this retrospective audit was to find out if proper motivation-based teaching of students via the development of AKUTNE.CZ's serious games can help retain graduates of the Faculty of Medicine of Masaryk University (FMMU) for the AIM specialty.

Methods: Motivation-based teaching and the learning-by-doing concept were applied to a subject called *Individual Project*. Our topic, *The Development of the Multimedia Educational Portal, AKUTNE.CZ*, has been offered since 2010. The objective has been the development of supportive material in the form of interactive algorithms, serious games, and virtual patients for problem-based learning or team-based learning lectures aimed at acute medicine. We performed a retrospective questionnaire evaluation of all participants from the 2010-2017 period, focusing on their choice of medical specialty in 2017. The data were reported descriptively.

Results: We evaluated 142 students who passed *Individual Project* with topic *The Development of the Multimedia Educational Portal, AKUTNE.CZ* during 2010 to 2017. In this period, they developed up to 77 electronic serious games in the form of interactive multimedia algorithms. Out of 139 students in general medicine, 108 students (77.7%) had already graduated and 37 graduates (34.3%) worked in the AIM specialty. Furthermore, 57 graduates (52.8%) chose the same specialty after graduation, matching the topic of their algorithm, and 37 (65%) of these graduates decided to pursue AIM.

Conclusions: Motivation-based teaching and the concept of learning-by-doing by the algorithm/serious game development led to the significant retention of FMMU graduates in the AIM specialty. This concept could be considered successful, and as the concept itself can also be well integrated into the teaching of other medical specialties, the potential of motivation-based teaching should be used more broadly within medical education.

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KEYWORDS

problem-based learning; virtual patients; anesthesiology; intensive care; specialization

Introduction

Changes in Medical Education

Medical education, in general, is undergoing a significant shift from traditional methods (eg, example, textbooks, lectures, bedside teaching) to a more comprehensive approach using new teaching methods such as problem-based learning (PBL), scenario-based learning (SBL), team-based learning (TBL), and including modern information and communication technology tools such as e-learning, computer simulations, and virtual patients (VPs). The concept of VP itself is quite old but is still existent and initiating discussions about its role in the future of medical education [1-4]. VPs are often used for PBL and SBL concepts, which can have a lot of local particularities depending on their implementation, differing from school to school and variant to variant. Different modifications of these PBL and SBL methods are the current subjects of vast pedagogical researches, including multiple randomized studies [5-13]. A complex Cochrane systematic review on the use of the VP concept in medical education is being prepared. The protocol of the forthcoming review was published recently [14]. The new approach, with more focus on students, especially PBL and SBL using VPs, has been shown to improve the learning skills of medical students and residents over traditional methods [15,16]. Although good evidence in support of a particular education innovation may exist, it is rarely instrumental in decisions to adopt that innovation [17]. Therefore, there is still a wide chasm between student demand for modern and Web-based education and the availability of trained faculty to teach. The design of the learning interface is also important and will significantly affect the learning experience for the student [6,7,13,18]. However, what is often underestimated is the importance of motivation in medical education. We found only 3 relevant studies devoted to this topic [19-21] and it is one of the reasons why we decided to perform this audit.

Limitations in the Teaching of Anesthesiology and Intensive Care Medicine

Anesthesiology and intensive care medicine (AIM) is a dynamic and time-pressured environment with high demands on firm team communication and leadership, accurate clinical reasoning, and often immediate decision making [22]. Collaborative reasoning occurs in clinical practice but is rarely developed during education [15,23]. The traditional possibilities of practical teaching are mostly very limited because of the inherent nature of the specialty, which requires face-to-face hands-on training [24,25]. Real-time training in critical care units or operating rooms is very problematic for student teaching programs. The lack of time, space, opportunity for learning with mistakes without risk for the patient, and big count of students in one study group make education in this field of medicine trickier. On the contrary, it also gives us a bigger drive for the development of modern, virtual, and educational tools, which together with traditional education and simulation training could be the right concept of education.

Structure of Anesthesiology and Intensive Care Medicine Teaching at the Faculty of Medicine of Masaryk University

As in most European universities, the Faculty of Medicine of Masaryk University (FMMU) in Brno, Czech Republic, takes only 2 weeks of practice (40 hours) and weekly lectures (half in the fourth and half in the fifth year of study) for AIM teaching in the entire curriculum. For people more interested in this field, there is an option to pass nonmandatory subjects such as anesthesiology, intensive medicine, and pain therapy, each with 1 week of practice (20 hours). In addition, FMMU in cooperation with the educational Web portal, AKUTNE.CZ, offers the unique possibility to focus more on acute medicine within another subject. The teaching subject named *Individual Project* is the obligatory part of the pregradual curriculum of FMMU and is mandatory for registration of final exams. It can be finished at any time between the third and fifth study year. The student has to prove his/her ability to elaborate a student project for the chosen topic under the leadership of the supervisor. *Individual Project* is *terminus technicus*. The student can work on the project alone or in a group of other students but each student is evaluated individually. Since 2010, the topic, *The Development of the Multimedia Educational Portal, AKUTNE.CZ*, has been offered [26]. The objective was to develop supportive material for PBL, SBL, and TBL lectures aimed at acute medicine [27-29]. The supportive material takes an interactive algorithmic form of VP, the development methodology of which is exactly determined (see Study Context in Methods). It aims to develop essential characteristics of any physician dealing with acute patients—algorithmic thinking and correct clinical reasoning. This so-called learning-by-doing concept is motivation-based for both the students and supervisors. It uses the potential of teaching students who wanted to be educated by teachers who want to teach them.

Highly Motivated Students

We have considered all students who decided to take up our topic in the *Individual Project* subject as highly motivated students. It has been said that it is one of the most challenging topics, especially for its high time requirements. Therefore, only motivated students enroll. This can be an advantage as well as a limitation at the same time (see Discussion). The recruitment of highly motivated students for clinical practice is an important goal for every teacher of pregradual education.

Objectives

The primary goal was to find out if the proper motivation-based teaching of students can help retain graduates for a certain field of medicine (AIM in our case).

The secondary goal was to find out how big is the concordance between the algorithm topic and postgraduation specialty choice.

The tertiary goal was to find out what percentage of all Czech AIM trainees are graduates who have passed our learning-by-doing concept.

Methods

Participants

Our study takes the form of a retrospective monocentric audit on the FMMU. For the audit, we invited all the highly motivated students we have worked with to enroll, that is, all students and physicians who have passed our topic in the subject, *Individual Project*, provided by AKUTNE.CZ during the 2010-2017 period. This was the only inclusion criterion for the audit. We contacted all of them via email with a request to answer our questions (Figure 1). All the contacted participants agreed to participate in the audit and data processing. Next, we performed the evaluation of answers focusing on their choice of profession and specialization in medicine in 2017. According to the concept of our study and the subject of evaluation, no ethics committee statement was required after approval by the dean of FMMU.

As a relevant source of medical population statistics data, we used the most recent database available in January 2018, *Czech Republic Healthcare: A Brief Survey of Anesthesiology and Intensive Medicine, 2006-2016*, from the Institute of Health Information and Statistics of the Czech Republic.

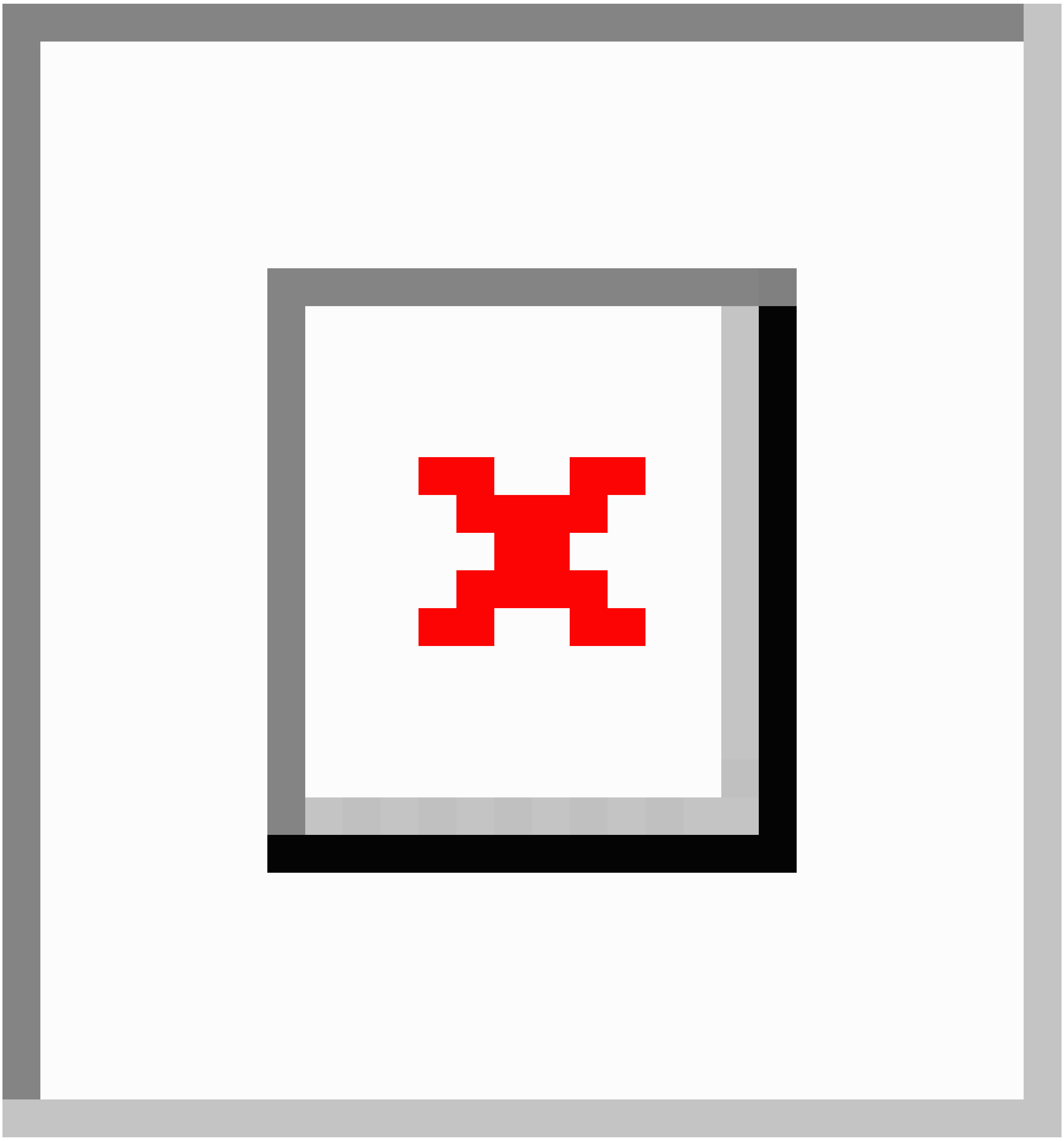
The data were reported descriptively using Microsoft Excel 2007 (Microsoft Corporation).

Study Context

The education portal, AKUTNE.CZ, is an important part of the Medical Faculties Network's (MEFANET's) contents [26]. It aims to be a comprehensive source of information and education materials, covering all aspects of acute medicine for undergraduate and postgraduate students of the medical and health professions [29].

The supportive material takes an interactive algorithmic form of the VP (further in the text referred shortly as an algorithm), the development methodology of which is exactly determined [27,28]. Students work in small groups of 2 to 3 members under the supervision of a physician working in the AIM specialization. The estimated time spent on actual work to produce 1 interactive algorithm is approximately between 20 and 100 hours (approximately 2 semesters). The team members devote their time to collaborative work, essential meetings, and self-study. The first draft of an algorithm is in the form of a text document describing the situation at each decision node. The next phase consists of designing both correct and incorrect decision options, inclusive of comments to the correct and incorrect answers. After incorporating the supervisor's remarks and adding the values of vital signs and physical and laboratory examinations, the whole algorithm is entered node by node into a BackOffice Web application (Institute of Biostatistics and Analyses of FMMU, Czech Republic), together with supplementary multimedia files. Each algorithm must contain 1 picture in each node and at least 1 video, all made by the team members themselves. The resulting algorithm is generated in the form of an HTML5 document, and it is always created in a bilingual version, Czech and English. Before publishing, each algorithm has to undergo an internal review process and, subsequently, it is sent to an external reviewer, experienced clinician, or academic staff member. After incorporating the reviewer's comments and remarks, the algorithm is supplemented with metadata to be published on the AKUTNE.CZ education portal and indexed by the MEFANET Central Gate [27-29]. All the algorithms are available on the Web and are free of charge for academic use in PBL, SBL, and TBL sessions or e-learning. Each algorithm or even its nodes can be referenced with the use of a URL. For better visualization, see the algorithm workflow schema in Multimedia Appendix 1.

Figure 1. Questionnaire for the students and physicians who passed the topic *The Development of the Multimedia Educational Portal, AKUTNE.CZ* of *Individual Project*, provided by AKUTNE.CZ.



Results

Students' Evaluation

We evaluated all 142 students who passed the *Individual Project* subject with topic *The Development of the Multimedia Educational Portal, AKUTNE.CZ* during the 2010-2017 period. As all 142 students provided us with data, the total number of participants is the same as the number of invited students, that is, 142. In this period, they developed up to 77 electronic VPs in the form of interactive multimedia algorithms. All contacted participants agreed to participate in the audit and data processing.

Among the 142 students, 3 students who had studied Dentistry were excluded from further statistics. As depicted in Figure 2, out of 139 students in general medicine, 108 students (77.7%) had already graduated, 27 (19.4%) were still studying (after December 2017), and 4 (2.9%) finished their studies unsuccessfully. In addition, 37 graduates (34.3%) worked in AIM specialization and 68 (63.0%) worked in other clinical fields of medicine. Furthermore, 3 (2.8%) graduates worked and travelled abroad and so were counted as unemployed in medicine.

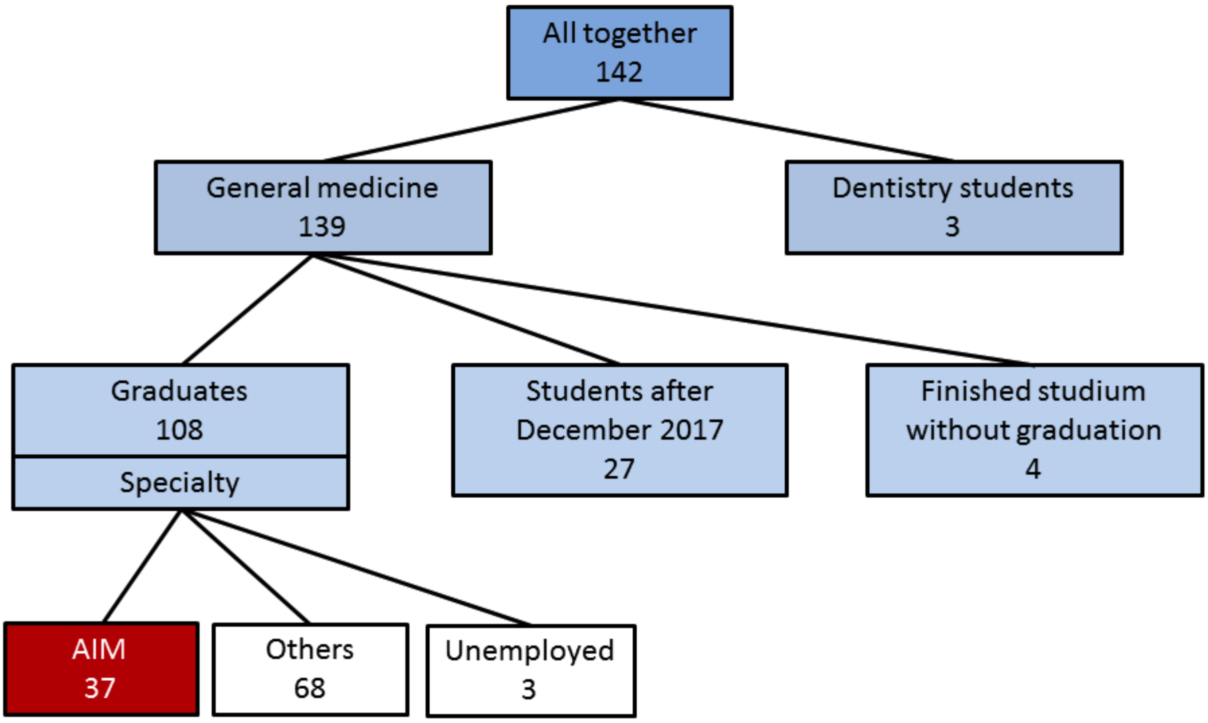
Algorithm's Topics

The topic of each algorithm is dealing with an AIM issue but some of them are multidisciplinary (20 only AIM, 18 internal medicine, 18 surgery and traumatology, 8 gynecology, 6 pediatrics, 3 internal and pediatrics, 1 surgery and gynecology, and 3 dentistry). A total of 57 graduates (52.8%) chose more or less the same specialty after graduation, matching the topic of their algorithm. Furthermore, 37 (65%) of these graduates decided to pursue AIM. We see this finding as very interesting as it can support our hypothesis about the relationship between undergraduate motivation and retention in a specific field of medicine after graduation.

Anesthesiology and Intensive Care Medicine Specialty in the Czech Republic

In 2016, there were 41,600 physicians in the Czech Republic; AIM employed 2207 (5.30%) of them. A total of 525 (23.79%) were trainees without a finished AIM specialization. Approximately one-third of highly motivated students, after completing their studies, selected AIM as their specialization and helped to expand the number of AIM physicians in the Czech Republic. Since 2010, our graduates accounted for 7.04% of all AIM trainees in the Czech Republic. Presently, 4 of them have already finished their specialty training and 16 have the root test certificate (fulfilling AIM specialty in the Czech Republic takes at least 5 years).

Figure 2. Students who passed *The Development of the Multimedia Educational Portal, AKUTNE.CZ* topic of *Individual Project* during 2010-2017. Numbers are in absolute figures. AIM: anesthesiology and intensive care medicine.



Discussion

Principal Findings

To the best of our knowledge, this is the first study focused on the motivation of medical students to be an anesthesiologist using the learning-by-doing concept.

There is no doubt that modern, interactive, multimodal learning and teaching methods are needed in medical education [9,16,17,30,31]. Moreover, motivation-based teaching uses the potential of teaching students who want to be educated by teachers who want to teach them. It is important to evaluate how successful and effective these new methods can be as the importance of motivation is often underestimated [19]. The choice of medical specialty after graduation is certainly multifactorial. However, if we assume that all graduates deal with the same issues (vacancy, salary, and place for living) when looking for a job, then the leading factors for the choice of medical specialty would be enthusiasm and inner feeling of suitability for a certain field of medicine. Enthusiasm is strongly influenced by motivation-based teaching. The learning-by-doing concept provides insight into a certain subject and helps answer the question of personal suitability. Therefore, the retention of highly motivated students in some field of medicine could be an appropriate indicator of the success of the motivation-based teaching concept. The topic, *The Development of the Multimedia Educational Portal, AKUTNE.CZ*, in the *Individual Project* subject is mainly focused on AIM. According to the results, 37 (34%) graduates chose AIM as their further specialization. However, if we take only the group of 57 graduates whose specialty choice is matching the topic of their algorithm, then 37 (65%) of them chose AIM as their specialty after graduation. As there are 43 specialties in the Czech Republic, retention of 65% of graduates for only 1 specialty does not appear as a coincidence. We are aware of the limitations (see Limitations); however, this may indicate that our method of motivation and teaching is effective and successful enough not only to attract motivated students but also to retain them in a certain field of medicine.

Our VPs are content-rich interactive algorithms and their development requires systematic work. The algorithm development itself, as a part of the learning-by-doing process, supports critical thinking and decision making and these are the 2 key skills that are useful, especially for AIM physicians. The creation of such algorithms is extremely demanding, time consuming, and often accompanied by ambiguity and hesitation. The algorithm team meets regularly to check the progress and workflow according to the timetable. A settled schedule motivates students to work systematically and helps them to develop the sense of time management. There are 3 group meetings of the entire AKUTNE.CZ team in a semester to motivate, simulate a creative environment, and provide an open-minded discussion forum. The whole team is built on positive motivation. If students are more interested in AIM, we provide them with the possibility to visit different conferences and other educational events for specialists to gain better insight on our field of medicine. Moreover, AKUTNE.CZ supports a contest, *The Algorithm of the Year,* to reward authors of the 3 best algorithms. Another important aspect is teamwork based on a close collaboration between students and the leader, who is always a doctor working in the AIM specialization. It enriches students' theoretical knowledge of the practical experience that is provided by the leader. This slightly informal microenvironment also provides students with a great opportunity to meet an AIM professional on a different basis and ask questions about the real nature of the AIM specialty, advantages, and disadvantages, which they would probably never consult with the university authority. We understand that this is very important for decision making and self-evaluation of the inner feeling of suitability for the AIM specialty. Finally, the algorithm is published on the AKUTNE.CZ educational portal website. The fact that students actually produce something *tangible* and even help with the development of multimedia learning material for others can further affect their attitude to academic work for evidence-based medicine.

According to our results, 37 (34%) graduates chose AIM as their further specialization and thus formed 7.1% of all young AIM trainees in the Czech Republic. The lack of physicians and their outflow abroad is a negative phenomenon not only in the Czech Republic but also in other developed countries. Therefore, it is very important to encourage qualified physicians. The Czech Republic, as one of the postcommunist countries, cannot offer salaries as compared with other western European countries. These negative economic aspects may perhaps be somehow alleviated by supporting motivation for needed professions. We believe that motivation-based teaching concepts in medical faculties can make a significant contribution to solving problems with the lack of physicians from the very beginning.

Limitations

We are aware of the limitations of this study. The audit was just monocentric but it is a new concept of teaching, originally used in FMMU and now spread and used for teaching some other medicine faculties in the Czech Republic. We tried to provide an analysis comparing the number of graduates in total and the number of graduates who decided to pursue AIM in the FMMU before 2010 and after the application of our concept. Unfortunately, the faculty is lacking statistical information about the graduates' specialization choice. The choice of medical specialty after graduation is certainly multifactorial. Financial factors, free positions, the distance of clinic/hospital from living place of graduates, and others certainly affect decision making of the specialty. In addition, for some graduates, this may become the leading factor. Another limitation can be a passive preselection of highly motivated students, who themselves decided to choose our topic in the subject, *Individual Project*. Therefore, it can be assumed that they were already interested in AIM. However, on the contrary, is it not the right group of students who should be motivated and encouraged to retain in the AIM specialty?

Further investigation is definitely needed. We believe that the positive results of a motivation-based education approach can help motivate others to continue to systematically work with undergraduate students.

Conclusions

Motivation-based teaching and the concept of learning-by-doing led to significant retention of graduates of FMMU in the AIM specialty (overall 34% and 65% in the group of graduates where specialty choice was matching the algorithm topic). Since 2010, our graduates formed 7.1% of all trainees in the AIM specialty in the Czech Republic. This concept could be considered as successful, and as the concept itself can be certainly well interpolated for the teaching of other medical specialties as well, the potential of motivation-based teaching should be used more broadly within medical education.

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Authors' Contributions

All authors contributed to this paper equally and approved the final text of the manuscript. MK was responsible for coordinating the writing of the manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Algorithm workflow schema.

[JPG File, 301KB - games_v7i2e10155_app1.jpg]

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Abbreviations

AIM: anesthesiology and intensive care medicine
MEFANET: Medical Faculties Network
FMMU: Faculty of Medicine of Masaryk University
PBL: problem-based learning
SBL: scenario-based learning
TBL: team-based learning
VP: virtual patient

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Original Paper

Effect of an Augmented Reality Ultrasound Trainer App on the Motor Skills Needed for a Kidney Ultrasound: Prospective Trial

Florian Ebner[1,2], MD, PhD; Amelie De Gregorio[3], MD; Fabienne Schochter[3], MD; Inga Bekes[3], MD; Wolfgang Janni[3], MD, PhD; Krisztian Lato[3], MD

[1]Helios Amper Klinikum, Dachau, Germany

[2]University of Ulm, Ulm, Germany

[3]Obstetrics and Gynecology Department, University of Ulm, Ulm, Germany

Corresponding Author:
Florian Ebner, MD, PhD
Helios Amper Klinikum
Klinikstrasse 15
Dachau, 85221
Germany
Phone: 49 8131 764298
Fax: 49 8131 764296
Email: dr.ebner@web.de

Abstract

Background: Medical education is evolving from "learning by doing" to simulation-based hands-on tutorials.

Objective: The aim of this prospective 2-armed study was to evaluate a newly developed augmented reality ultrasound app and its effect on educational training and diagnostic accuracy.

Methods: We recruited 66 medical students and, using imaging and measuring a kidney as quality indicators, tested them on the time they needed for these tasks. Both groups used textbooks as preparation; in addition, the study group had access to a virtual ultrasound simulation app for mobile devices.

Results: There was no significant difference between the study arms regarding age (*P*=.97), sex (*P*=.14), and previous ultrasound experience (*P*=.66). The time needed to complete the kidney measurements also did not differ significantly (*P*=.26). However, the results of the longitudinal kidney measurements differed significantly between the study and control groups, with larger, more realistic values in the study group (right kidney: study group median 105.3 mm, range 86.1-127.1 mm, control group median 92 mm, range 50.4-112.2 mm; *P*<.001; left kidney: study group median 100.3 mm, range 81.7-118.6 mm, control group median 85.3 mm, range 48.3-113.4 mm; *P*<.001). Furthermore, whereas all students of the study group obtained valid measurements, students of the control group did not obtain valid measurements of 1 or both kidneys in 7 cases.

Conclusions: The newly developed augmented reality ultrasound simulator mobile app provides a useful add-on for ultrasound education and training. Our results indicate that medical students' use of the mobile app for training purposes improved the quality of kidney measurements.

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KEYWORDS

ultrasound trainer; mobile device; mobile apps; augmented reality; kidney; sensitivity and specificity; ultrasonography; education; simulation training; telemedicine

Introduction

Background

Sonography is a well-established diagnostic tool and is sometimes used for small interventions. It is a noninvasive treatment or diagnostic tool, is cost effective, has no side effects, and is clinically valuable in nearly all medical disciplines. Technical developments in recent years mean that the examiner requires more skill and knowledge in using ultrasound [1]. As a result, the demand for educational lectures and courses has increased [2-4]. Traditionally, medical journals, hands-on tutorials, and theoretical lectures have been used for keeping doctors up-to-date. One of the difficulties of sonography compared with other imaging technologies is the complex motor hand-eye coordination required. Students are commonly trained in coordination on healthy volunteers with limitations in time and availability. Malignancies or abnormalities are most likely not present in healthy volunteers. Therefore, various models for simulation have been developed [5]. The expense of such simulators, unfortunately, limits their availability for practice.

Due to the technical advances in mobile phones and the common acceptance of augmented reality (AR)—mainly due to the popularity of the video game Pokémon Go [6]—new training possibilities via smartphone have opened up [7]. AR is commonly defined as extended information on a real-world image, compared with virtual reality (VR), which is completely separated from the real-world image. With AR it is now possible to simulate a patient on a smartphone and imitate a sonographic examination.

Objective

The aim of this cohort study was to determine whether there was a difference in hand-eye coordination and motor skills needed for ultrasound examination between 2 groups of medical students with and without exposure to a VR ultrasound training app for the time and measurements of a kidney ultrasound.

Methods

Participants and Procedure

Using the Consolidated Standards of Reporting Trials (CONSORT) and Standards for Reporting of Diagnostic Accuracy Studies (STARD) statements as guidelines, we designed this cohort study, called Ultraschall App Study (UPPS), to evaluate a newly developed ultrasound AR simulator mobile app on its educational and diagnostic effect on 2 cohorts of medical students. The curriculum is an annual schedule resulting in same-year students attending a summer and a winter semester.

We recruited 66 medical students and split them into 2 groups. We determined the starting group (the control group) by flipping a coin. We recruited the control group in the summer term between April and June 2016. We recruited the study group between August 2016 and November 2016 (no student courses are offered in June and July). Participation in the study was offered during a mandatory weekly course in obstetrics and gynecology sonography but participation was voluntary. The lecturer was the same over the recruitment period. No student declined.

Initially a questionnaire was handed out and participants self-estimated their ultrasound experience (self-estimation was scored on a scale from 0 to 10, with 0 indicating no sonographic experience and 10 indicating a very experienced student). A tutor explained the aim of the following 60-minute study time, and participants were provided with theoretical knowledge for self-study (*Sono-Grundkurs* [8]). The participants were told to aim to visualize and document the reference or tutor kidneys with an ultrasound at the end of this lecture. Study group students additionally had access to the iOS-based AR ultrasound simulator app installed on 3 handheld devices. The study app was designed using the mobile device's gyroscope to simulate the motion of an ultrasound transducer and was provided in the native language (German). The text files were also translated into English, Hungarian, Romanian, Italian, and Polish by native-speaking colleagues. With the app, training ultrasound motor skills does not need a proper ultrasound machine, nor a patient. It is also independent of time and location, as the mobile device needed is a smartphone or a tablet. Figure 1 shows the virtual patient as displayed on the tracker pattern and the ultrasound mode once the mobile device is close to the virtual skin, showing a kidney scan simulation (Multimedia Appendix 1). One patient was simulated for this proof-of-concept study.

After 60 minutes of self-study in a group, the participants had a brief tutorial on the use of the ultrasound machine (GE Voluson Expert 8, General Electric, GE Medical Systems, Solingen, Germany) set to kidney scan. Then the participants were asked one by one to scan and measure both kidneys of the tutor as accurately as possible and document their scan with the normal images. Starting time was the beginning of the examination, and finishing time was the time stamp on the last picture. We used this time frame to compare the 2 groups and as an internal quality control for the self-estimation. After students finished the documentation, they were given a written multiple choice test (range 0-6 points) to evaluate their theoretical knowledge. Finally, the study group was asked to assess the AR mobile app on a scale from 0 to 10 regarding the usefulness of the app, their recommendation regarding its use, and problems they encountered (responses: yes, no, not yet).

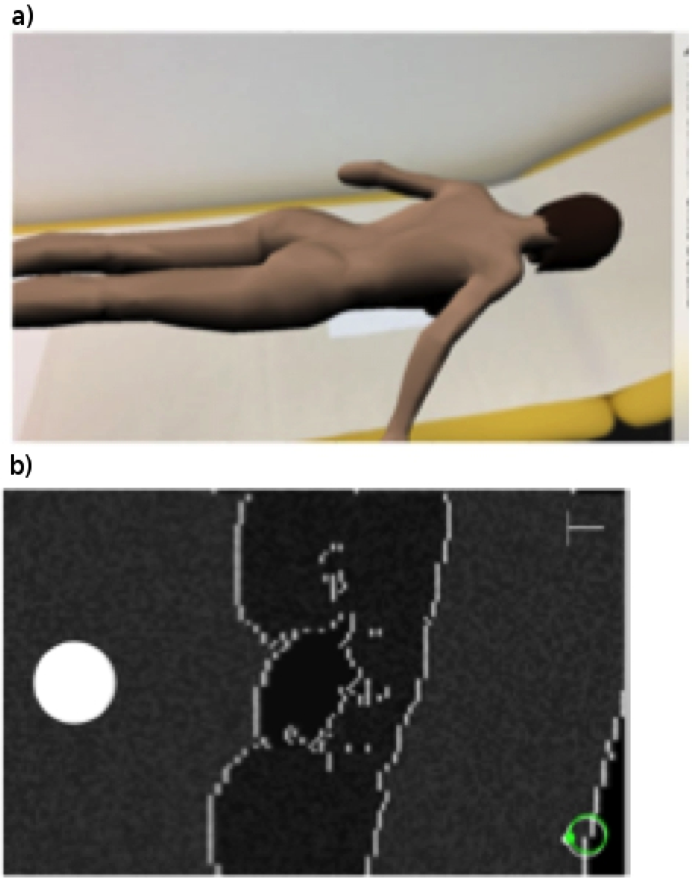
Prior to the study recruitment, we consulted the University of Ulm ethics committee, which exempted the study from ethical approval.

Statistical Analysis

For the statistical analysis, we used IBM SPSS Statistics for Windows, version 21.0 (IBM Corporation). The descriptive statistic used likelihood tables with absolute and relative likelihood for nominal data and with median and area for ordinal-scaled and metric data.

Due to the significant difference in the distribution of the multiple metric variables (kidney measurements, examination time, age, semester, ultrasound experience, multiple choice test results, and app rating) from the norm (Shapiro-Wilk test), we used exclusive nonparametric statistical analysis. We compared the groups for nominal-scaled (categorial) data or rates with chi-square tests (Fisher exact test; variable: successful visualization of the kidney). We applied Mann-Whitney *U* test to test the differences between 2 independent groups referring to ordinal-scaled or metric data (kidney measurements, examination time, age, semester, ultrasound experience, and multiple choice test results).

Figure 1. (a) The virtual patient and (b) the kidney scan as shown on the mobile device. The white spot documents the image, T indicates which plane needs documenting, and the green circle indicates the correct position. If the image is off, the circle is red, thus providing immediate feedback to the user. See also a video of the app in Multimedia Appendix 1.



We used boxplots for ordinal-scaled and metric data for intergroup visualization (kidney measurements, examination time, age, semester, ultrasound experience, and multiple choice test results). In these plots, the horizontal line is the median and the box symbolizes 50% of the data (interquartile area). The whiskers of the box and whisker plots had a maximum length of 1.5 times the interquartile area. If all data are within these borders, then the minimum and maximum value determine the length of the whisker. All values outside the whiskers are marked as dots. We calculated correlations for ordinal-scaled and metric data according to Spearman rho (ρ). All *P* values are 2-tailed and *P*<.05 was considered significant.

Results

Participant Characteristics

A total of 66 medical students participated in our study; 33 students were assigned to the control group and 33 to the study (app) group. There was no significant difference in the parameters age, dominant hand, and sex between the 2 groups (Table 1). Because we recruited participants in the summer/winter term, members of the study group were on average in their ninth semester (range eighth to 12th semester) and the control group were in their eighth semester (range seventh to 10th semester). Prior ultrasound knowledge was similar (study group: median score 2, range 0-4.5; control group: median score 2, range 0-4; *P*=.66). In the study group, more students self-reported AR experience (7/33, 21% vs 1/33, 3%; *P*=.05; Table 1) than in the control group.

Group Result Comparisons

The study group visualized the kidneys in all cases on both sides, whereas the control group did document the kidney in 7 cases (1 right and 6 left). This resulted in a significant difference for the left kidney (Fisher exact test, *P*=.02). Additionally, the measurement of the kidney length was significantly different (right kidney: study group median 105.3 mm, range 86.1-127.1 mm, control group median 92 mm, range 50.4-112.2 mm; *P*<.001; left kidney: study group median 100.3 mm, range 81.7-118.6 mm, control group median 85.3 mm, range 48.3-113.4 mm; *P*<.001; Figure 2). The measuring time period (in seconds) was not significantly different (study group median 351 s, range 155-563 s, control group median 302 s, range 103-527 s; *P*=.26; Figure 3). There was an inverse correlation between the time needed for kidney documentation and self-reported ultrasound experience (ρ=–.28, *P*=.04). The results of the multiple choice questionnaire were not significantly different between the 2 groups (*P*=.13).

Table 1. Comparison of the variables of the 2 groups.

Variable	Control group (n=33)	Study group (n=33)	*P* value
Age (years)			.97[a]
Median	24	24	
Range	22-31	22-30	
Sex, n (%)			.14[b]
Male	13 (39)	19 (58)	
Female	20 (61)	14 (42)	
Dominant hand, n (%)			.24[c]
Right	33 (100)	30 (91)	
Left	0 (0)	3 (9)	
Self-reported experience with augmented reality, n (%)			.05[c]
Yes	1 (3)	7 (21)	
No	32 (97)	26 (79)	
Theoretical multiple choice test, mean score	36.8	30.2	.18[d]
Ultrasound experience score (scale 0-10)			.66[a]
Median	2	2	
Range	0-4	0-4.5	

[a]Mann-Whitney *U* test.

[b]Chi-square test.

[c]Fisher exact test.

[d]Asymptotic significance (2-tailed) of the Mann-Whitney *U* test.

Figure 2. Box and whisker plots comparing longitudinal (a) right kidney and (b) left kidney measurements (in millimeters). The reference kidney is marked at 101 mm (right kidney) and 110 mm (left kidney).

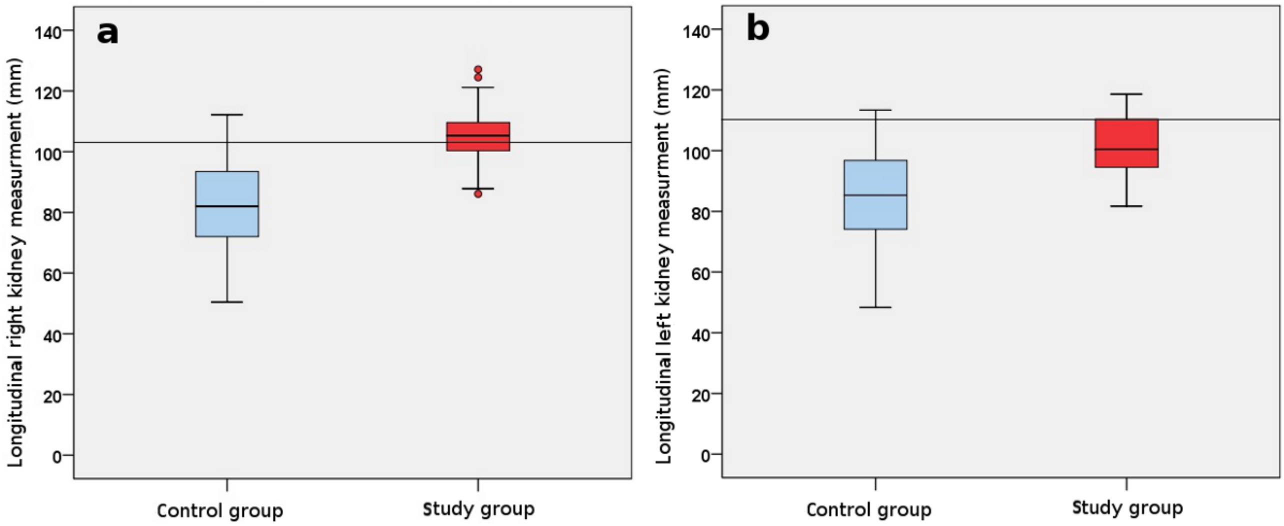
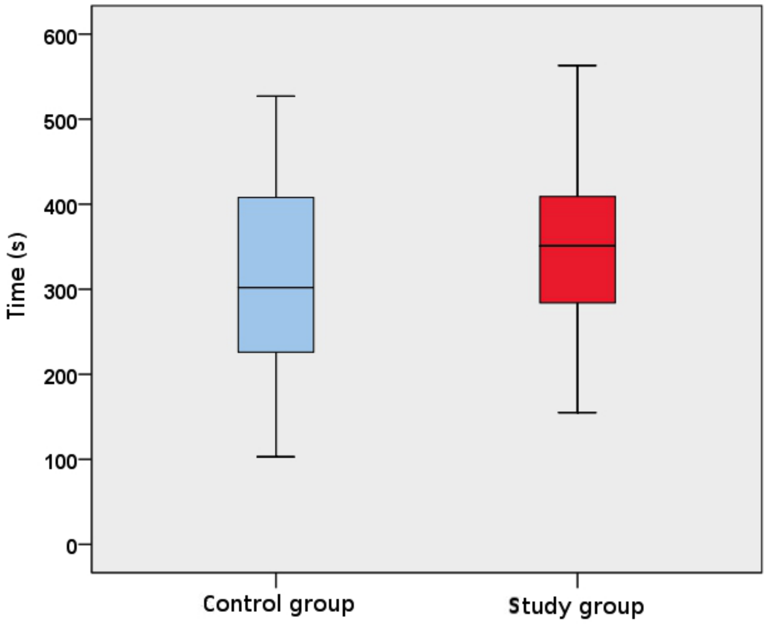


Figure 3. Box and whisker plot of the time to document both kidneys (in seconds).



Discussion

Principal Findings

The transition from reality to virtuality has been described as a reality-virtuality continuum by Milgram et al [9]. The amount of additional virtual information varies depending on the needs and what it is being used for. In AR, additional information is displayed or initiated with barcodes, imaging recognition software, or trackers to enhance reality. This is in contrast to VR, where everything is computer generated.

Computer games and smartphones have helped bring VR and AR into daily life. Google Glass, a brand of smart glasses, received mixed responses when first announced [10,11]. Pokémon Go, introduced in the summer of 2016, could be considered the AR breakthrough. Since then, the usability of AR and VR have continuously improved [12]. The "Pokémon Go effect" may have played a role in our study, as the questionnaires showed an increase in self-reported AR knowledge in the study population (from 3% in April to 21% in September) [6].

Over the last 20 years, several generations of medical apps have been produced. Whereas the first generation were expensive and had potential clinical uses [13], improvements in chip and smartphone technology enabled new possibilities for education and learning using the advances made in the entertainment industry and implementing them in medical education [14]. AR can enhance the learning curve for ultrasound education in combination with theoretical knowledge and motor skills. To date, to our knowledge no smartphone app that can simulate an ultrasound examination has been developed.

To objectively evaluate the effectiveness of the mobile app, we targeted medical students with next to no ultrasound experience but with knowledge of anatomy. The weekly obstetrics and gynecology introductory course proved ideal. This introductory course is mandatory for fourth-year medical students before they are exposed to clinical work. Students tend to communicate with each other about their clinical courses and the examinations at the end. To ensure that the 2 groups in the study would be independent, with minimal exchange of information about the study, we spread the recruitment time over 2 university teaching periods (summer and winter semesters), with 1 semester per group (control and study). Starting with the control group also coincidentally ensured that the following students were not biased by earlier participants. Students also could not find the app in the online store as a training opportunity outside the study, which would have introduced further bias. The tutor was approached by 2 control students once word about the app had spread among the students. We chose the kidney due to its superficial position, homogeneous size (with the normal adult kidney being 100-120 mm [8]), and importance in various disciplines. Little time is needed to learn to do a kidney ultrasound. Our study group's measurements were closer to the values of the reference kidneys within an hour of practice and significantly different from the general visualization of the kidney.

In a prospective randomized trial, Celebi et al showed similar teaching effectiveness for student tutors and ultrasound experts [3], so our aim was to provide a first evaluation of the effectiveness of a mobile app without a tutor's supervision. The results add to the observations of Celebi et al and others by showing positive effects after 60 minutes of autonomous practicing [15-17]. As opposed to Celebi et al [3] and Ritter et al [16], our study focused on practicing motor skills by using a smartphone or tablet.

Furthermore, our study included a practical test by visualization of the kidney and a multiple choice questionnaire. Despite the published possibilities of combining practical evaluation methods for teaching interventions, such a practical test is not commonly used for evaluation in a clinical course [17] but, from our point of view, is an essential step for a successful clinical lecture. The significant differences between the control and intervention group in the visualization and measurements show the need for such a hands-on approach. A tutorial including hands-on practice prepares students better for clinical routine, even without further tutor supervision.

Limitations

Despite these positive results, we identified the following points that need to be addressed. Recruitment bias can only be minimized, as random allocation for each participant is not possible in our setting. The students were assigned on a weekly schedule to a group, and interaction between the groups was known to occur. To reduce this bias, the study protocol grouped the participants per semester. Unfortunately during the study period, the Pokémon Go game became available and VR bias might have had an effect on the results [6]. Students with more VR experience may have better motor skills with their mobile devices due to additional training. As there was no difference in scan time or app rating before and after the release of Pokémon, such a bias seems unlikely. But, with the expected increased use of AR mobile apps, this effect might influence future studies, as a VR-naive comparable control group would be impossible to recruit. On the other hand, the kidney measurements differed between the 2 subgroups and this study, which was not designed to differentiate between preexisting motor skills and app-trained skills. This needs to be evaluated with either a larger number of students or a baseline question regarding the participants' gaming habits.

The 2-armed study protocol could be further criticized. There is, to our knowledge, no evidence-based statement for medical education trials, so we wrote the study protocol with the CONSORT and STARD statements as guidelines. The mobile app was designed to enhance the learning experience with a textbook by enabling the student to practice his or her motor skills and experience the theoretical facts on screen. This is in line with the results of the Extended Focused Assessment with Sonography for Trauma (eFAST) study [18], which showed no benefit for mobile e-learning compared with traditional learning. eFAST focused on the difference in theoretical learning and not on the motor skills as in our trial. The cost of developing such an app can be criticized. As the trial version of this app is available at no cost, we disagree with Nilsson et al [18] and do see a cost effectiveness for motor training, especially because the time of tutors, costs for ultrasound machines, and secondary costs (eg, room, missed outpatient clinic) are minimized with this app and no other cost-effective motor skills training method is available. Also, after app training, time is saved by improved imaging and, ultimately, diagnosis in the clinical setting. Besides those savings, the app development was the biggest cost factor. With only 1 organ and only 1 individual (eg, no variation in subcutaneous fat tissue) in the app, the costs surely outweigh the benefits per user, but there is the potential to simulate more difficult clinical cases such as obese patients, cardiac scans, or fetal organ screening in future studies.

We could have applied the Objective Structured Assessment of Ultrasound Skills criteria like Tolsgaard et al [19] applied them for a structured examination of the lung. Here the ultrasound federations could help future studies by providing variables. These proposed benchmarks based on current teaching models provide an expert's feedback on imaging quality. A mobile app could support the expert by guiding the user to the "ideal" image, ultimately providing rapid feedback and improving image quality beyond the current expectations regarding time and practice. This approach adapts individual differences in the learning curve [4,20] by being independent of expertise, time, location, and place. This freedom could be appealing to a wide range of students, and our results also show no sex difference in the acceptance of the app. With this home-based learning, the app could be used to prepare participants prior to an ultrasound course in order to maximize the learning effect.

Conclusion

We found that students can be trained in the motor skills needed for ultrasound examination using an AR app. Within a short training period, participants documented the kidney significantly better. The main advantage of the app is the freedom to train without a patient and a real ultrasound machine. With the implementation of immediate feedback on imaging quality and various scenarios and patients, such apps could be a valuable enhancement of lectures, courses, and textbook-based learning. This should result in more effective learning and improved clinical skills. Further benefits include the freedom to train in terms of time, model or patient, and place at a reasonable cost.

Conflicts of Interest

FE has been the honorable medical adviser for the company programming the app with reimbursement of travel costs. The other authors declare no conflicts of interest.

Multimedia Appendix 1

Video of the training app.

[MP4 File (MP4 Video), 4MB - games_v7i2e12713_app1.mp4]

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Abbreviations

AR: augmented reality
CONSORT: Consolidated Standards of Reporting Trials
eFAST: Extended Focused Assessment with Sonography for Trauma
STARD: Standards for Reporting of Diagnostic Accuracy Studies
UPPS: Ultraschall App Study
VR: virtual reality

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Original Paper

Comparing the Effects on Learning Outcomes of Tablet-Based and Virtual Reality–Based Serious Gaming Modules for Basic Life Support Training: Randomized Trial

Emin Aksoy[1], MSc, MD, PhD

Acibadem Mehmet Ali Aydinlar University, Center of Advanced Simulation and Education, Istanbul, Turkey

Corresponding Author:
Emin Aksoy, MSc, MD, PhD
Acibadem Mehmet Ali Aydinlar University
Center of Advanced Simulation and Education
Kayışdağı Cd No. 34
Istanbul, 34752
Turkey
Phone: 90 5052685158
Fax: 90 2165004200
Email: emin.aksoy@acibadem.edu.tr

Abstract

Background: Serious gaming is recognized as a training tool due its potential for a risk-free educational environment. There is still limited research about using serious gaming modules for emergency skills training.

Objective: The aim of this study is to compare the effects on the knowledge level of participants after using a tablet-based serious game and a virtual reality (VR)–based serious game for Basic Life Support using a pretest/posttest method.

Methods: The study was designed as a randomized trial comparing pretest and posttest results. A tablet-based and VR-based serious game with identical content was used for 40 participants. Over half of them (22/40, 55%) were included in the VR group and just under half (18/40, 45%) were in the tablet group. Student *t* test and Wilcoxon signed rank tests were used to determine the relation between the dependent and independent variables. In order to determine the effect size of the results, the effect size calculator (Cohen *d*) for *t* test was used. There is a significant difference between pre- and posttest results in both groups (*P*=.001; Wilcoxon).

Results: Mean posttest results were significantly higher in both groups. The posttest results were significantly higher in the VR group in terms of pre- and posttest changes (*P*=.021; Student *t* test).

Conclusions: Past research studies have shown that serious gaming presents a favorable additional tool for medical education. The results indicate that both serious gaming modules are effective and that VR-based serious gaming is more efficient in terms of learning outcome than tablet-based gaming.

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KEYWORDS

serious gaming; virtual reality; health care education

Introduction

In recent decades, new educational techniques have been adapted to address the constantly changing needs and expectations of educators and learners due to advances in technology. A reason for this shift was that students traditionally must learn the same thing at the same time, with the result that classes and training sessions are frustratingly hard for some and too easy for others [1]. The predominance of interactive learning tools over static reading material exercises has been shown as more effective [2]. It has also been shown that game technologies can positively affect learning performance, with learners quickly mastering and applying new skills and information, thinking laterally and strategically [3]. Experimental studies have largely supported the effectiveness of the game-based learning approach [4,5].

Medical students' experience and attitudes towards video games were investigated in a recent study with the conclusion that medical students held exceptionally ideal perspectives about the use of serious games [6]. But there still is limited research focused on the use of serious gaming modules for emergency training.

During the initial stages of their training, medical students, nurses, and other health providers are introduced to international Basic Life Support (BLS) algorithms. Traditional courses consist of theoretical lectures followed by hands-on training on a cardiopulmonary resuscitation (CPR) manikin. Considering the increasing use of computer-based education tools in medical education and the worldwide encouragement of teaching BLS Guidelines with video/personal computer (PC) self-learning courses with negligible or no educator training, we aimed to compare the efficacy of a tablet-based module and a virtual reality (VR)–based serious gaming module on BLS training. Mentors can use the simulated content provided by VR to empower trainees to participate in the learning process [7]. Due to the capacity of VR to attract learners and completely draw them into a virtual world, educators are frequently willing to use VR-based learning modules in learning activities [7]. In addition, the use of VR for training provides a safe learning environment, since it minimizes the physical risks of real-life training while enlarging the scope of learning and expanding trainees' motivation. The 3DMedSim tablet-based BLS serious gaming app and 3DMedSim VR-based BLS serious gaming modules offer another viewpoint for BLS training and provide trainees dynamic learning by immersing the learner in an environment that reproduces realistic emergency situations. Both systems are compatible with the European Resuscitation Council (ERC) 2015 Algorithm.

The aim of this study is to compare the effect of the knowledge level of participants after using the tablet-based serious game for BLS and the VR-based serious game for BLS with the help of a pretest and a posttest.

Methods

This study was designed as a randomized trial comparing pretest and posttest results of participants. After approval by the Ethical Committee of Acibadem Mehmet Ali Aydinlar University, 50 first-semester students of Acibadem Mehmet Ali Aydinlar University Vocational School for Paramedics volunteered to participate in this study. The participants (N=50) were randomly divided into two groups with 25 participants each. Since we had some dropouts due to personal reasons, we ended up with 22 of 25 (88%) participants in the VR group and 18 of 25 (72%) in the tablet group using the tablet version of our serious game. The participants were informed about the study and filled out consent forms. None of the participants received any prior education about the ERC 2015 BLS algorithm and had no prior VR experience. The 3DMedSim tablet-based BLS serious gaming app and 3DMedSim VR-based BLS serious gaming module identical content and difficulty level were used for this study. Both serious gaming modules were developed and created by our center, and these modules have been used for training the last 3 years.

Students from both groups had to complete a pretest to assess their prior knowledge on BLS procedures. After the BLS training, students in both groups then had to take a posttest to assess their acquired knowledge. The content of the pre- and posttest is shown in Table 1. The difference between the pre- and posttest was the scrambled order of questions and answers.

Student *t* test and Wilcoxon signed rank test were used to analyze the results in order to determine the relation between the dependent and independent variables. The analysis was performed using MedCalc Statistical Software version 12.7. In order to determine the effective size of the results, the effect size calculator (Cohen *d*) for *t* test was used.

The tablet version of the BLS serious game module is a multilingual serious game app with 3D and interactive features, based on the ERC 2015 Guidelines. The training module guides the user step-by-step through a scenario. The user has to go through a training mode first followed by the self-test mode. When using the serious game module, the user is not in passive reader/learner mode. The user is first instructed about the correct actions to be taken and then expected to interact with the software and "play" the rescuer role interactively. The user was expected to finish one stage correctly before continuing with the next one. The app is implemented as a 3D real-time game allowing the user to interact and see the scene from different angles. A few screen captures from the Adult BLS Module are shown in Figure 1.

Once the user successfully finishes the training module, the user has to complete the self-test module. Unlike the training module, the user is not given hints or instructions to follow and is expected to perform the correct steps with correct timing. Login usernames and passwords were sent to the participants by email, after they had downloaded the serious game from the Web by using iTunes or Google Play. The results of the participants were stored with the help of the learning management system. The participants' results were downloaded from the learning management system of the serious game module and converted to an MS Excel file.

The VR-based version uses a 3D interface instead of the 2D interface used for the tablet-based version. The educational content, scoring system, and flow of the scenario of the tablet-based and VR-based versions were totally identical, as both versions had to be compatible with the international BLS algorithm, ERC 2015 Basic Life Support Protocol [8]. The only difference was the display type used for serious gaming. Due to hygienic issues, the VR goggle's inner surface had to be disinfected each time that a new trainee initiated the game with VR. This procedure was not necessary for the tablet-based version. The other difficulty faced by the VR system was that more time was needed to load the game compared with the tablet-based version.

Table 1. Content of the multiple-choice test for Basic Life Support (BLS).

Questions	Points
1. The compression to ventilation ratio for one rescuer is the following:	10
a. 30:1	
b. 15:2	
c. 30:2	
d. 15:1	
2. The 2015 American Heart Association guidelines for cardiopulmonary resuscitation (CPR) recommended BLS sequence is the following:	10
a. Airway, Breathing, Check Pulse	
b. Compressions, Airway, Breathing	
c. Airway, Breathing, Compressions	
d. Airway, Check Pulse, Breathing	
3. The proper steps for operating an automated external defibrillator (AED) are the following:	10
a. Turn on the AED, attach AED pads, analyze the rhythm, stand clear, and deliver shock	
b. Turn on the AED, attach AED pads, shock the patient, and analyze the rhythm	
c. Check pulse, attach AED pads, analyze rhythm, deliver shock to the patient	
d. Attach electrode pads, check pulse, shock the patient, and analyze rhythm	
4. After delivering the shock with AED, what should be the next step?	10
a. Check pulse again	
b. Ventilate only	
c. Do chest compressions	
d. Proceed with CPR	
5. The initial BLS steps for adults are the following:	10
a. Assess the individual, call 112 and get AED, check pulse, and start CPR	
b. Check pulse, give rescue breaths, assess the individual and use AED	
c. Assess the individual, give two rescue breaths, defibrillate and start CPR	
d. Assess the individual, start CPR, give two rescue breaths and use AED	
6. The critical characteristics of high-quality BLS are the following:	10
a. Not interrupting	
b. Starting chest compressions within 10 seconds of recognition of cardiac arrest	
c. Pushing hard and fast	
d. All of the above	
7. The second rescuer has arrived with the AED and turned it on. What should be your next step?	10
a. Place the pads over the victim’s clothes	
b. Wait for advanced care to arrive before continuing use of the AED	
c. Shock the victim	
d. Place the pads on the victim’s bare chest	
8. Which one is the most critical component of CPR?	10
a. Airway management	
b. Rescue breathing	
c. Chest compressions	
d. All of the above	
9. Use a head tilt chin lift to open the airway in an adult victim if you do not suspect a cervical spine injury.	10

Questions	Points
a. True	
b. False	
10. Which artery should you check for pulse in an adult?	10
a. Radial artery	
b. Femoral artery	
c. Carotid artery	
d. Brachial artery	

Figure 1. Screen captures from the Adult Basic Life Support Module.

A very important risk factor of the VR version was the potential problem of dizziness. Similar to motion sickness, VR sickness is caused due to mismatch between the visual and vestibular systems. VR-based serious game scenarios must take this risk into account. Participants were warned about this risk on their written consent forms before using the VR-based version. The VR-based version of the serious game was used in a special room with soft flooring material and special walls covered with soft material in order to minimize the risk of trauma in case of dizziness problems. With the technical improvements of today's head-mounted systems (HMD) for VR, the risk of dizziness has been minimized due to the higher resolutions and higher refresh rate of the screens used for VR systems compared with the previous generation of similar systems. Unlike the tablet-based BLS module, the VR system is much more immersive. The user can move within the 3D scene freely and after a while feels a part of the scene (Figure 2).

Figure 2. Screen capture from the virtual reality–based serious gaming module.

Results

Pretest results indicated that students in both groups had similar prior knowledge. Statistical analysis was performed using the MedCalc Statistical Software version 12.7.7 [9]. For comparison of two non-normally distributed dependent groups, Wilcoxon signed rank test was used. As seen in Table 2, there is a significant difference between average pre- and posttest results in both groups (*P*=.001). In order to calculate the effect size of the results, Cohen *d* has been used [10]. The effect size of the VR results are significantly higher compared with the tablet version.

Mean posttest results were significantly higher in both groups. The difference between the pre- and posttest results were significantly higher in the VR group, and these data were statistically significant (*P*=.021; Student *t* test) as seen in Table 3 and Figure 3.

Table 2. Statistical analysis of pre- and posttest results of the tablet personal computer (PC) and virtual reality (VR) group using Wilcoxon test and effect size calculation results with Cohen *d*.

Group	Pretest		Posttest		*P* value[a]	Cohen *d*
	Mean (SD)	Median (min-max)	Mean (SD)	Median (min-max)		
VR	47.7 (9.5)	46 (37-69)	65.4 (10.6)	62 (46-88)	<.001	1.75
Tablet PC	53.2 (11.3)	54 (31-69)	62.1 (8.5)	62 (46-77)	.001	0.89

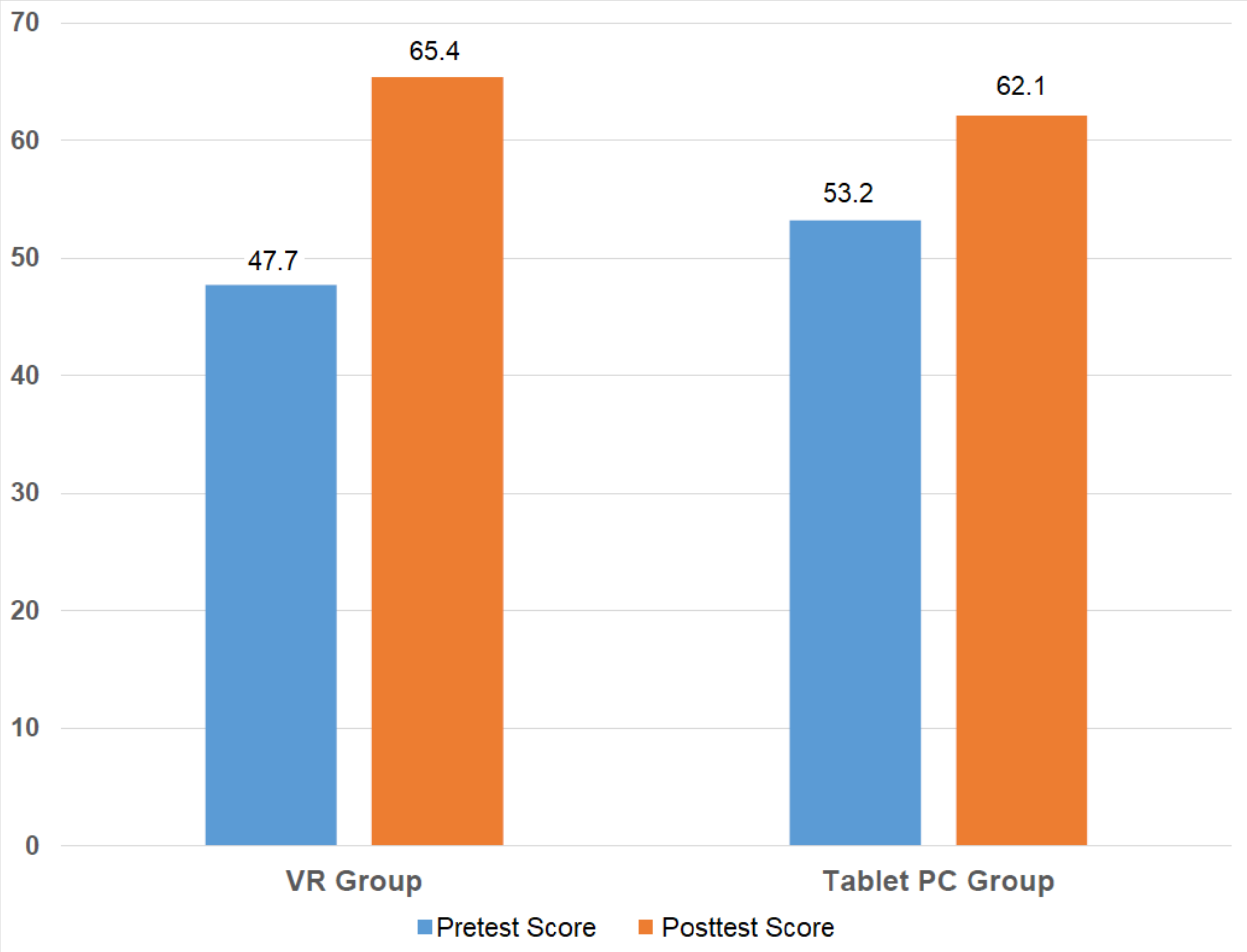
[a]Wilcoxon test.

Table 3. Difference between the pre- and posttest results of the virtual reality (VR) and tablet personal computer (PC) group.

Variable	VR		Tablet PC		*P* value[a]
	Mean (SD)	Median (min-max)	Mean (SD)	Median (min-max)	
Difference between pre- and posttest results	–17.6 (11.6)	–16.5 (–42 to 8)	–8.9 (11.1)	–8 (–24 to 16)	.021

[a]Student *t* test (*P*<.05).

Figure 3. The difference between pre- and posttest results of the tablet (PC) and virtual reality (VR) groups.



Discussion

Principal Findings

In various studies, it was shown that the positive impact of active learning methodologies includes increased content understanding, enhanced learning, long-term memory retention, and enhanced collaboration and motivation [11-13]. Serious gaming provides both interaction and motivation for digital learners [1,5]. These technologies are being widely used in different areas, but there are a few studies in medical education [14-18]. Our study also shows us that tablet-based and VR-based serious gaming for the BLS training of health care students are effective in terms of active learning.

Bandura's Social Learning Theory suggests that individuals learn from each other, by means of perception, impersonation, and demonstration [19]. This theory acts like a bridge between behaviorist and cognitive learning theories because it incorporates attention, memory, and motivation [19]. By using VR-based gaming modules, learners engage with the virtual world and learning material thus providing learners a maximum amount of perception, impersonation, and demonstration.

In our study, we used the 3DMedSim tablet-based BLS serious gaming app and 3DMedSim VR-based BLS serious gaming modules, which are both highly interactive and provide self-directed learning opportunities.

In a study by Fabio Buttussi, the impacts on knowledge acquisition and level of self-efficacy, engagement, and presence by using different kinds of displays were evaluated [20]. The displays used in this study were a standard desktop monitor, a narrow field HMD with 3 Degrees of Freedom (DOF) tracker, and a wide field HMD with 6-DOF tracker. Results demonstrated that the display type had a critical impact on the level of engagement and presence [20].

In our study, we also found that because of immersion effects, VR HMD was more effective compared to the tablet PC. However, we did not evaluate the maintenance of knowledge after a 2-week period.

In the study by Moro et al, both VR and augmented reality (AR) were found to be equally effective for learning anatomical structures as tablet PCs while having the advantage of higher levels of learner immersion and engagement [21]. Trainees' views of each learning mode and adverse effects experienced were recorded. The differences between in VR, AR, or tablet based versions were found to be insignificant. Adverse effects like headaches, dizziness, and blurred vision were detected in some participants.

In a study by Akshay Vankipuram et al, it was also shown that use of VR-based training modules for medical education could improve the skills of clinicians [22]. There is still limited research about using VR in emergency skills training. Serious gaming was found to be an effective method for active and self-directed learning and for teacher and students' time constraints by giving the educator and learner flexibility in the learning environment [17]. VR has been perceived for its huge educational potential in risk-free clinical training [23].

In another study, it was mentioned that the use of these technologies has upgraded the adequacy of medical education and training and raised the level of diagnosis and treatment [24]. Another study reveals that VR-based Advanced Cardiac Life Support training can provide a learning experience similar to face-to-face training [14].

Our study supports the importance and positive effect of using serious gaming as a complementary tool in medical education. Table 3 shows that the results favor VR-based serious gaming due to its immersive effect on the participants (P=.021 calculated with Student t test when P<.05). When the effect size was calculated by using Cohen d [10], the effect size of the VR results is significantly higher compared with the results of the tablet version (Table 2).

Limitations

One the limitations in our study was that the participants were not familiar with using VR-based systems in the beginning of the study compared to the group using tablet PCs for the serious gaming app. Due to widespread use of tablets and mobile phones in the Turkish population, participants encountered no difficulties using the tablet-based app. VR-based systems are rather new technologies with very few people having access to this technology at this time in our country. Training on using VR hardware was given to participants before using the VR-based game. Although there was a risk of feeling dizzy while using the VR-based version, this problem was not encountered during this study. Since we used the highest flickering rate and screen resolution with today's technology, we did not encounter any kind of clinical problems such as dizziness or headache during VR training.

Conclusions

We contend that VR-based serious gaming provides interactivity and a higher level of presence due to higher immersion levels, therefore it is already being widely used for training purposes in many areas. But there are only a few apps being used in medical education. Despite this, we believe that VR-based serious gaming modules will have many areas of application in medical education as well. Our study indicates that serious gaming has a positive effect on the learning outcome of digital learners. Further studies need to be performed on the effectiveness of serious gaming in health care training.

Conflicts of Interest

None declared.

Multimedia Appendix 1

CONSORT - EHEALTH checklist (V 1.6.1).

[PDF File (Adobe PDF File), 2MB - games_v7i2e13442_app1.pdf]

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Abbreviations

AED: automatic external defibrillator
AR: augmented reality
BLS: Basic Life Support
CPR: cardiopulmonary resuscitation
ERC: European Resuscitation Council
HMD: head-mounted display
PC: personal computer
VR: virtual reality

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Viewpoint

Interactive Narrative in a Mobile Health Behavioral Intervention (Tumaini): Theoretical Grounding and Structure of a Smartphone Game to Prevent HIV Among Young Africans

Kate Winskell[1], PhD; Gaëlle Sabben[1], MPH; Christopher Obong'o[2], PhD

[1]Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA, United States

[2]School of Public Health, University of Memphis, Memphis, TN, United States

Corresponding Author:
Kate Winskell, PhD
Hubert Department of Global Health
Rollins School of Public Health
Emory University
1518 Clifton Road
Atlanta, GA, 30322
United States
Phone: 1 4047275286
Email: swinske@emory.edu

Abstract

The increasing availability of smartphones, including in low-income countries, offers an unprecedented opportunity to reach individuals with innovative health promotion interventions. Electronic games delivered via smartphone offer promising avenues for sexual health promotion and HIV prevention, especially for young people. By giving players real agency in a virtual and safe environment, well-designed games can provide a level of experiential learning unparalleled by many other behavioral interventions. The design of effective games for health relies on multidisciplinary insight and expertise. However, relatively few studies discuss the theoretical understanding underlying their intervention. Making explicit the theoretical grounding of a game-based intervention allows articulation of assumptions and strategies, anticipation of outcomes, and evaluation of impacts (including intermediate effects), thereby increasing understanding of pathways to change, with a view to contributing to the development of more effective games. It also helps strengthen the credibility and improve the accountability of games for health. We present the multidisciplinary theoretical framework—integrating intervention design, mediators, and behavioral outcomes—and the structure of an HIV prevention game for young African adolescents that has shown promise in a randomized pilot study in Western Kenya. The central component of *Tumaini* (*hope for the future* in Kiswahili) is an interactive role-playing narrative in which the player makes choices for characters that determine how their paths unfold. In addition, a series of mini-games reinforce skills, and the "My Story" component links the game world to the player's own life and goals, and a reward system motivates continued play. With its "choose-your-own-adventure" format, *Tumaini* is intended to be replayed so that players can experience the consequences resulting from different choices made in the role-playing narrative. Grounded in theories of narrative and applied communication and in social behavioral theories, especially Social Cognitive Theory, *Tumaini* is designed to help young adolescents acquire the information, skills, and motivation they need to avoid and reduce sexual risks. We close by situating *Tumaini* within discussion of the theory and practice of using interactive narrative in health promotion, with a view to furthering theoretical elaboration.

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KEYWORDS

mHealth; serious games; games for health; narrative; HIV; adolescence; sub-Saharan Africa; behavioral theory; narrative theory

Introduction

A third of all new adult HIV worldwide infections occur in young people aged between 15 and 24 years [1]. Although young women are particularly vulnerable because of biological and structural factors, both sexes too often lack the understanding, skills, and guidance they need to successfully navigate the physiological, emotional, social, and behavioral changes and challenges of adolescence and avoid or reduce risks to their sexual health. They need help in identifying new risk situations to which they will be exposed and in which gendered pressures—structural, normative, group, and interpersonal—constrain their ability to make healthy choices. Prominent cultural scripts may leave them feeling little control over sexual situations [2,3], and they may need to learn how to exercise agency. Ideally, they need opportunities to prepare for potential risk situations through interventions informed by behavioral theory that allow them to build and practice skills.

Although role-play has been a staple of evidence-based group HIV prevention interventions, in-person exercises have limitations when it comes to successfully simulating real-life contextualized experience [4]. They are dependent on the capacities of the facilitator and the imaginative faculties of participants and may be perceived as embarrassing or inauthentic. A growing number of group interventions for HIV prevention among adolescents have shown efficacy in a randomized controlled trial (RCT) in a high-resource country. However, such interventions may face adaptation and implementation challenges, including the high cost of facilitator-led group sessions and their poor record of translation from RCT to community setting [3]; these challenges may be magnified in low-resource settings.

Computer-based (electronic health or “eHealth”) interventions for HIV prevention have shown positive effects on behavioral mediators and clinical outcomes [5,6]. A new generation of interventions on mobile devices often incorporate higher levels of interactivity and personalization, recognized as increasing effects on behavior. Increasingly accessible smartphone technologies make it possible to engage youth—at scale and at low cost—in culturally adapted prevention interventions that require little personnel to implement with consistent quality, have high entertainment and motivation appeal, and incorporate automated data collection. These prevention interventions can be integrated into everyday life and have the potential to allow young people to learn about sensitive issues in a private virtual space and to determine the pace of their own learning, ideally in line with their developmental needs. A systematic review has shown the potential of interventions using new digital media to improve adolescent sexual and reproductive health [7]. There is recognition of the need for future research to build a stronger evidence base by tracking behavioral outcomes, rather than mediators, over longer periods [7,8]. There is also a need to build an evidence base for such interventions in low- and middle-income countries, where limited research has been conducted to date.

Digital games represent a promising intervention strategy, especially for youth HIV prevention [9]. By allowing players, through interactivity, to experience real agency in a virtual and safe environment, well-designed games provide a level of experiential learning unparalleled by many other interventions. A small but growing body of evidence supports the effectiveness of games for health outcomes [10-13]. In their 2015 systematic review and meta-analysis of games for sexual health, DeSmet et al [11] found positive effects, albeit of small size, on behavioral determinants. They concluded that greater reliance on immersive and health-promoting features that draw on behavioral change and educational gaming literature (specifically role-playing, simulation, and narrative) is likely to increase the effectiveness of the next generation of games for sexual health.

Several studies have questioned the adequacy of current behavioral theories to account for the distinctive affordances of health promotion using new digital media. It has been suggested that there is a need to develop new theories that acknowledge the multidisciplinary background and genealogy of such interventions [7,14-16]. However, few interventions—including games for health—are explicit about their theoretical foundations [8], thereby limiting the potential to elaborate new models and increase the understanding of mechanisms of effect, essential for the development of more effective intervention approaches [17]. Where theory is addressed, it focuses on psychosocial constructs from behavioral science theory and rarely incorporates multidisciplinary perspectives [16].

We present here the theoretical grounding and structure of a smartphone game for HIV prevention using interactive narrative that has shown promise in a pilot randomized study [18]. The game is designed to provide African preadolescents (aged 11-14 years) with the knowledge, motivation, and behavioral skills to delay sexual initiation and use a condom from first sex. *Tumaini* (*hope for the future* in Kiswahili) is a game-based intervention built around an extensive interactive narrative or *choose-your-own-adventure* (CYOA) format. It was created with a US commercial game developer and with input from US-based and Kenyan specialists in adolescent sexual and reproductive health and from Kenyan preadolescents and their parents. *Tumaini* is grounded in distinctive research on HIV-related narratives written by young people aged 10-24 years across sub-Saharan Africa. The narratives, submitted by tens of thousands of young Africans to Global Dialogues/Scenarios from Africa [19] scriptwriting contests, provide age-specific insight into youth sexual culture, decision-making, and sociocultural context [20-27].

In a randomized controlled pilot study in Kisumu, Western Kenya, with 60 participants aged 11-14 years, intervention arm participants (n=30) played *Tumaini* over 50% longer than instructed, a mean of approximately 27 hours over a 16-day period [18]. Control arm participants received no intervention beyond any existing sex education from family, school, and peers [28]. The intervention arm showed significant gains in sexual health-related knowledge and self-efficacy (both $P<.001$), behavioral intention for risk-avoidance strategies and sexual risk communication ($P=.006$), and overall survey scores ($P<.001$) compared with the control arm 6 weeks postintervention. A postintervention survey revealed high subjective measures of the game’s value, relevance, and appeal, and postintervention focus groups with preadolescents and their parents identified a wide range of knowledge and skills they had gained. We present the theoretical grounding and structure of *Tumaini* here, with a view to furthering theoretical elaboration of both games for sexual health and games rooted in interactive narrative.

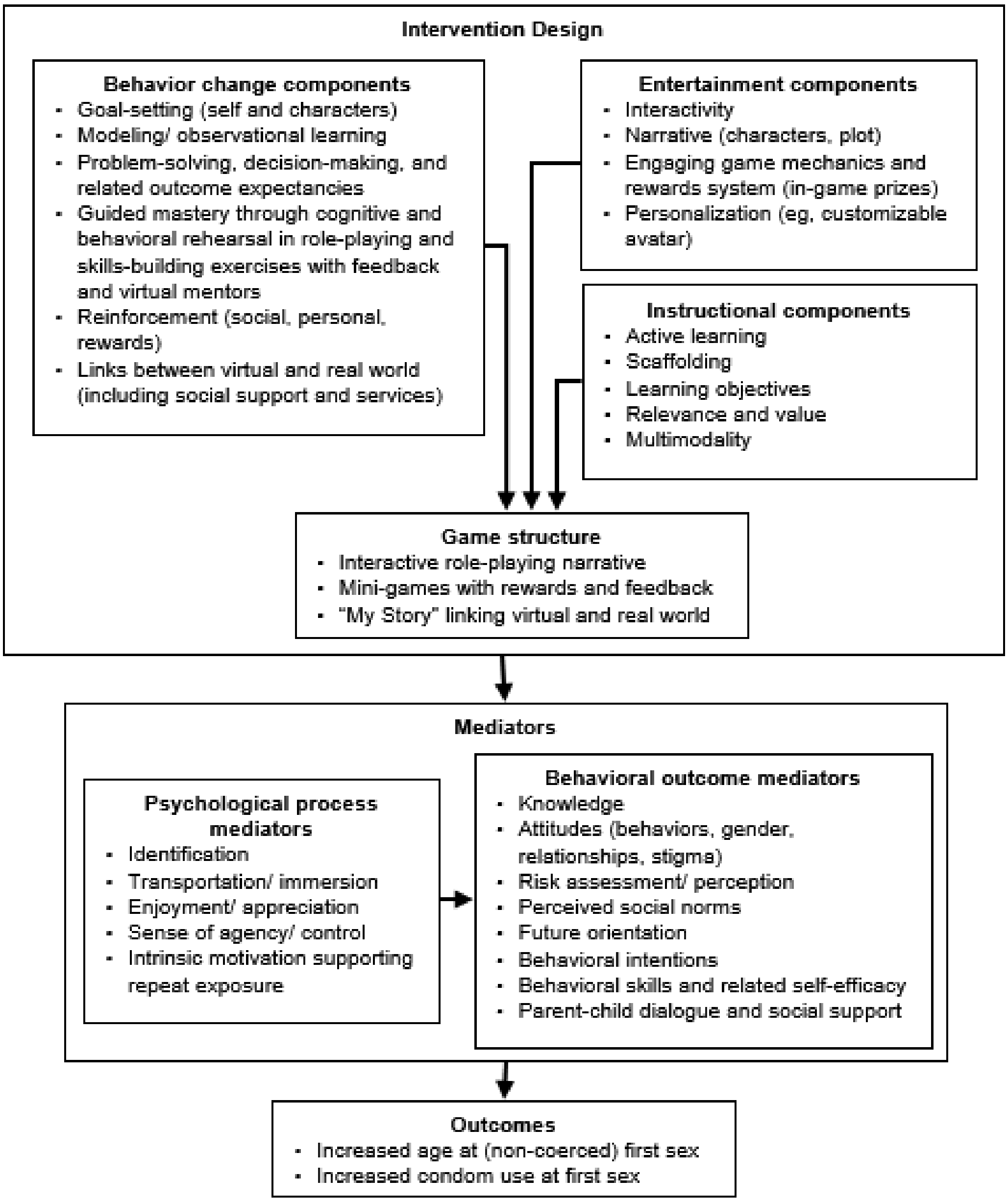
Theoretical Framework

Tumaini is grounded in (1) theory on narrative and narrative-based applied communication, (2) social behavioral theory and existing evidence-based HIV prevention interventions, and (3) principles of instructional design.

Following Thompson et al [29], the theoretical framework is divided into 3 parts: intervention design, mediators, and outcomes. In our theoretical framework (Figure 1), these are represented by (1) the entertainment components of intervention design and the psychological process mediators, (2) the behavior change components of intervention design and behavioral outcome mediators, and (3) the instructional components applied in intervention design. Although we separate the 3 sets of mediators for clarity and ease of measurement, they are interlinked and are integrated within the game structure and our overarching theory of interactive narrative and its effects.

Tumaini is made up of 3 integrated parts (Multimedia Appendix 1): (1) a central interactive narrative featuring 6 playable characters (3 male and 3 female characters) whom players guide into and through adolescence, making decisions that have short- and long-term consequences for the characters' lives, relationships, and health; (2) a set of mini-games that tie into the narrative and support and reinforce its core themes; and (3) "My Story," in which the player sets goals, plans how to achieve them, and reflects on how the game relates to his/her life and how he/she might apply the lessons learned to protect his/her future. To respect the integration of theory and design in our narrative-based intervention, we contextualize the mediators identified in our theoretical framework (which we subsequently italicize for ease of identification) within theory on narrative and narrative-based applied communication and within behavioral theories first, before describing its structure in greater depth.

Figure 1. Theoretical framework for Tumaini, an HIV prevention game rooted in interactive narrative.



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Narrative: Entertainment Components and Psychological Processing Mediators

New digital media provide platforms for unprecedented forms of interactive learning, facilitating learners' ownership of knowledge and skills and their application in real life. *Tumaini* 's CYOA structure combines *interactivity* with *narrative*, while incorporating *engaging game mechanics and rewards system*, and *personalization*, which are common features of games for health.

Narrative Processing

The past two decades have seen increasing interest in the use of narrative in social and behavior change communication [30], including games for health. There is growing recognition among practitioners and applied communication specialists of the opportunities narrative offers to contextualize learning within relevant, meaningful, and emotionally resonant situations and storylines, thereby increasing both audiences' motivation to engage with the subject matter and the potential for transferal of learning to real life. Communication scholars argue that narrative is easier to remember than non-narrative communication and also easier to understand and therefore more accessible [31]. It has the advantage of being closer than non-narrative communication to lived experience in its simultaneous appeal to multiple senses, to reason and emotion, to intellect and imagination, and to fact and value. Indeed, in narratives, we are able to "perfink," or perceive, feel, and think simultaneously [32].

Narratives have the potential to generate in us real and powerful emotions [33,34]: these allow us to live, experience, and learn vicariously, obviating the need to learn through direct personal experience. Through the embodied emotion that narratives generate, in large part through our *identification* with characters, the story experience becomes a personal experience. *Transportation* —whereby individuals suspend disbelief and are carried away imaginatively into the narrative's world—distinguishes the processing of narrative from other forms of communication [35]. Related to *immersion* in the game literature, transportation is believed to be a primary driver of the persuasive appeal of narratives, that is, the fact that narratives are more difficult to resist, counterargue, or refute than non-narrative communication and therefore have a greater impact on attitudes [36].

Transportation is recognized as an enjoyable experience; however, some scholars differentiate between *enjoyment*, a form of hedonistic pleasure, and *appreciation*, a form that is valued for being meaningful, moving, and/or thought-provoking [37]. Because they are pleasurable, narratives can provide a "self-motivating vehicle for information delivery" [38]. They also facilitate sense-making and recall, by providing a framework for organizing new knowledge that builds on existing knowledge or familiar situations. Narratives are particularly well-suited for conveying complex phenomena and processes, in part because of their ability to accommodate multiple voices and perspectives; this can make even complex processes seem "more accessible, intuitive and memorable" [38]. In addition, by contextualizing information, they can "create memory traces that automatically bring strategies to mind when those future contexts arise" [38].

Interactive Narrative

Beyond the emotional and cognitive participatory responses that narrative evokes (eg, by encouraging us to engage in anticipatory problem-solving) [39], some narratives—for example, CYOA novels—are deliberately constructed to be interactive. In contrast to a traditional narrative in which the author has complete control over the characters and plot progression, interactive narrative is "a story in which the reader has the opportunities to decide the direction of the narrative, often at a key plot point" [40]. In these narratives, the player assumes the dual role of audience for and coauthor of the story, shifting the power dynamic between audience and author [41].

Narrative-based public health interventions can foster *agency* on the part of the audience in a variety of ways, with a view to promoting critical thinking, problem-solving, and decision-making [30]. Within legacy media, role-play has traditionally assumed a central place in behavioral skills–building training. A striking example is Forum Theater, based on Augusto Boal's Theater of the Oppressed [42], in which the "fourth wall" is dissolved at a certain point in the action and audience members are invited to come on stage as "spectactors" and try out their own skills at resolving the conflict.

A recent account of the processes and outcomes of interactive narratives focuses on text-based stories, specifically CYOA books [40]. New communication technologies take the potential for interactive engagement with narrative to a new level by offering efficient and convenient interfaces and allowing audiences to assume an increasingly active role, influencing characters and events.

The empirical evidence about the processes and outcomes of interactive narratives is distributed across a range of media and is limited but growing. Interactivity in narrative has been linked to increased transportation, increased identification or empathy, and increased engagement through the added pleasure of agency or control [43,44]. Even in text-based interactive narratives (which do not offer the seamless transitions of electronic media), decision points do not appear to interrupt the process of transportation [40]. The audience "enacts rather than witnesses the story," and thereby "more deeply internalizes and personalizes the story events" [43]. As enjoyment is highly correlated with transportation, interactive narratives—by creating greater transportation—should be more enjoyable and lead to more sustainable change than traditional narrative forms [40].

Interactive narratives highlight the cause-and-effect relationships between the audience's decisions and the consequences that ensue. In their largely theoretical examination of the psychological processes and outcomes of reader engagement with interactive narratives, Green and Jenkins [40] focus on increased player control and concomitant looser narrative structure as key characteristics. In addition to increased agency and control, Green and Jenkins posit that the audience's response to interactive narrative is mediated through different roles of the self: as they make decisions for the characters, readers might reflect on similar situations in their own lives ("self-referencing"); they might explore possible selves and see how they feel and behave in different situations; and they might assume an increased sense of responsibility toward the characters. In their own empirical research, Green and Jenkins found that most people make decisions for a character based on what they personally would do in real life, by identifying with the character and putting themselves in his or her shoes, rather than by trying to understand a character's unique motivations.

Some studies have explored the potential of the increased empathy fostered by this process of perspective-taking to reduce stigma toward marginalized groups [45,46]. A study of the effects of an interactive narrative on attitudes toward undocumented immigrants [47] suggests that simply adopting another person's perspective in such a narrative may be an effective tool to help reduce prejudice toward marginalized social groups.

Some commentators frame interactivity in terms of experiential play that fosters curiosity, experimentation, and exploration, stressing entertainment and motivational dimensions [48]. A game that the audience can choose whether or not to play needs to be entertaining and *intrinsically motivating* [49], facilitating repeat exposure to the content. Repeat exposure is further facilitated by the potential narrative offers for parallel but superficially different storylines "that create interest, providing an opportunity for multiple exposures to critical material without making it seem redundant" [38]. This, in turn, helps to develop "gist" decision-making prior to or in the absence of conscious deliberation [50].

In our Theoretical Framework, these understandings of the opportunities afforded by interactive narrative translate into the following psychological process mediators: (1) *Identification;* (2) *Transportation/immersion;* (3) *Enjoyment/appreciation*; (4) *Sense of agency/control*; and (5) *Intrinsic motivation, supporting repeat exposure and attention/retention*.

Social Behavioral Theory: Behavior Change Components and Behavioral Mediators

Social Cognitive Theory

Social Cognitive Theory (SCT) [51] is distinctive among social behavioral theories not only on account of its comprehensiveness but also for the fact that it provides operational insight to guide intervention design. As a mark of the relevance of SCT to games for health, Bandura has explicitly extended his theory not only to entertainment-education [52] but also to interactive media, including electronic games [53], citing the need "to make creative use of the revolutionary advances in interactive technologies" [54].

SCT provides a holistic account of the mediators and mechanisms of social behavior change communication that is grounded in an understanding of human agency as operating within a broad network of sociostructural influences. Bandura distinguishes between direct and indirect (ie, socially mediated) pathways of media influence: in the indirect pathway, media links people to social networks that can provide ongoing guidance, as well as natural incentives and social support, thereby linking the media world with the real world.

A central principle of SCT is that humans learn not only through direct personal trial-and-error experience but also through social *modeling* (also known as *observational learning*), that is to say, by observing others perform a behavior, either in our immediate environment or through the mass media. Models are a source of "inspiration, competencies, and motivation" [52] and can transmit knowledge, values, and skills, along with new behaviors and coping strategies. Models are most effective when they resemble the intended audience. Observing others achieve desired outcomes through their actions can create *outcome expectancies* that serve as motivators (or in the case of failures, as disincentives) or *reinforcement*. In the case of interactive role-playing narratives, observation is combined with active problem-solving and decision-making. *Reinforcement* can also include the personal satisfaction or the social approval or disapproval that the behavior elicits (subjective norms) or, in the case of a game, the rewards system.

To enact behaviors, we need information and skills, but also a belief in our ability to use those skills, namely *self-efficacy*, the central mediator of behavioral change within SCT. The most effective way to instill self-efficacy is by combining modeling with *guided* opportunities to incrementally achieve *mastery*. Learning needs to be broken down into small manageable steps so that the participant gradually builds confidence. Through *repeat exposure* and practice with increasing challenges, we ideally learn incrementally how to manage setbacks and overcome obstacles with perseverance and effective strategies, without ever becoming demoralized.

Efficacy beliefs play an important role in shaping the course of people's lives by influencing their outcome expectations and *goal-setting* [55] and, therefore, the types of activities and environments they choose. *Future orientation* associated with goal-setting gives one's life direction, coherence, and meaning. We need both long-term and short-term goals to motivate and guide our behavior: goals have little impact unless they are translated into achievable subgoals and concrete plans and strategies for achieving them.

Because no 2 situations are alike, skills need to be adapted to suit varying circumstances. The necessary translation of observed learning to abstract skill is "greatly facilitated by having models verbalize their thoughts aloud as they engage in problem-solving activities," making the thoughts guiding their decisions and action available for adoption [56]. Bandura has commented that health education for youth has focused on providing facts and has not equipped children with the skills and efficacy beliefs to manage social and emotional pressures to adopt behaviors that are detrimental to their health and manage social relationships. Integrating guided mastery with family and community efforts to provide social support is ideal [53]. Mobile health (mHealth) interventions have tended to focus on stand-alone interventions at the individual level [57]. Commentators have cautioned against mHealth efforts making a virtue of exploiting the affordances of mobile technologies to offer stand-alone interventions and "to practice public health at increasing distances" from communities [58]. Particularly in the case of games for preadolescent populations, they must seek to promote *parent-child dialogue and social support*. This, in turn, can help reinforce *links between the virtual and real world*.

In our Theoretical Framework, these understandings translate into the following behavior change components: (1) *Modeling/Observational learning*; (2) *Problem-solving, decision-making, and related outcome expectancies*; (3) *Reinforcement (social, personal, and rewards)*; (4) *Guided mastery through cognitive and behavioral rehearsal in role-playing and skills-building exercises with feedback and virtual mentors*; (5) *Goal-setting (self and characters)*; and (6) *Links between virtual and real world*.

In addition, existing evidence-based HIV prevention interventions for youth provide the following behavioral mediators, drawing on theories including SCT, the Theory of Planned Behavior [59], and the Health Belief Model [60]: (1) *Knowledge*; (2) *Attitudes (behaviors, gender, relationships, and stigma)*; (3) *Risk assessment/perception*; (4) *Perceived social norms*; (5) *Future orientation*; (6) *Behavioral intentions*; (7) *Behavioral skills and related self-efficacy*; and (8) *Parent-child dialogue and social support*.

Constructivist Learning Theory and Curriculum Development

Drawing on a constructivist model [61], our Instructional Components overlap with SCT. They focus on *active learning* in a dynamic, but structured, learning environment designed to foster student meaning-making and problem-solving around specific *scaffolded learning objectives*. Storylines grounded in research on young Africans' narratives are designed to create *relevance* and *value*, while learning is distributed and reinforced across a range of *multimodal* (drawing on a range of sensory modalities) and complementary game components.

Game Structure

In the following section, we present the structure of *Tumaini*, which is made up of 3 parts: (1) an interactive role-playing narrative; (2) a set of mini-games; and (3) "My Story," in which the player reflects on how the game relates to his/her life.

The interactive role-playing narrative is about 3 boys and 3 girls who are aged between 11 and 14 years at the start of the game. Players role-play each of the 6 characters (male and female) as they age over the course of the 3 game levels, passing into or through adolescence. The characters face real-life challenges that the players are likely to face at some stage in their own lives. These include peer pressure; puberty; violence; and decisions about smoking, alcohol, drugs, and sex. The player makes choices for these characters and sees the consequences of those choices in the characters' lives. The game is made up of 18 chapters distributed over 3 levels. The outcomes of the players' decisions find expression in over 40 different potential epilogues across the 6 characters. Major decision points are designed to be meaningful and to drive the story (if incrementally so), increasing players' sense of agency.

The entire game comprises approximately 12 hours of discrete gameplay. It is designed to be replayed so that players can observe the outcomes of different decisions, exploring possible selves through the different characters and their various paths through the game. Replay is encouraged via the rewards system, such that additional prizes are awarded for completion of new decision paths. Cliffhangers at the end of each level are designed to stimulate curiosity, elicit anticipation of possible outcomes, and increase enjoyment/appreciation, thereby increasing intrinsic motivation.

The player is positioned immersively as a third-person character who is addressed directly by the playable characters (eg, "Do you ever feel unsure of yourself?") and has access to their thoughts. In addition to deciding the characters' actions from a brief menu of options in response to "What should I do/say?" prompts, the player is also invited to identify characters' feelings in response to "How do I feel?" prompts, fostering increased identification with characters, self-referencing, and emotional rehearsal. Each character has an older mentor, modeling adult-child dialogue, and social support. The mentor distills out attitudinal and behavioral learning from the experiences of the characters (eg, around gender, relationships, and stigma). Each chapter is accompanied by either a mini-game or a *My Story* component, and a prize is awarded for completion of each chapter or *My Story* component and for successful completion (a score of at least 80%) of a mini-game.

The mini-games are designed to build on the interactive narrative, reinforcing knowledge, skills, and related self-efficacy through guided mastery (cognitive and behavioral rehearsal through role-playing and skills-building exercises with feedback and virtual social support). Some of the mini-games are quizzes; some ask players to assess the risk of specific situations; some ask the player to respond to pressure situations; and some are jigsaws. The topics of the mini-games are connected to the topics in the role-playing story. For example, when the main story is about puberty, the players play the puberty game. When the character in the main story is being pressured by his friends to drink alcohol, players play a skills-based game about saying no to peer pressure.

In the mini-games, the player is challenged with questions of increasing difficulty and receives feedback, encouragement, and suggestions. Right answers are applauded, whereas wrong answers elicit a deflated sound, followed by feedback from 1 of the characters (eg, "You could have said..."). Reinforcement takes multiple forms: vicarious internal reinforcement is modeled through the playable characters and their outcomes, vicarious social reinforcement is modeled through the reactions of peers and mentors, and the players' learning is reinforced through growing personal mastery and in-game rewards.

The third part of the game is called "My Story." This component of the game asks players to think about different aspects of their personalities and to set personalized goals. It allows them to connect the knowledge and skills they learn in the game with their own lives. Like the mini-games, the topics for this part of the game are connected to the main role-playing story. For example, when the characters are considering what future goals they have, players are asked to identify their goals and what they can do now to help themselves reach them, reinforcing behavioral intentions. At the end of each chapter, a "bridge" question ("What about you?") links the chapter's narrative to the player's real world, encouraging cognitive rehearsal and connecting knowledge and skills to a personal decision-making framework infused with future orientation.

Discussion

Overview

We have shared the multidisciplinary grounding informing the design and the process and outcome mediators of *Tumaini*, which draws on insights from fields including communication, education, psychology, anthropology, educational gaming, and public health. Making explicit the theoretical grounding of a game-based intervention allows us to articulate our assumptions and strategies, anticipate outcomes and evaluate impacts (including intermediate effects), and thereby understand pathways to change, with a view to ultimately contributing to the development of more effective games. It also helps us to strengthen the credibility and improve the accountability of games for health and to help move the field forward. We now situate *Tumaini* in the context of comparable narrative or game-based interventions and within discussion of the theory and practice of using interactive narrative in health promotion, with a view to furthering theoretical elaboration.

The Role of Narrative in Games

The question of what role narrative should play in games for health has elicited divergent opinions [62]. Stories have played central or peripheral roles in serious games, often depending on the game's behavioral objectives and, concomitantly, its pedagogical approach. Narrative has tended to serve a secondary and, above all, motivational role in games for chronic disease prevention, where behavioral decision-making is more deeply rooted in habitual day-to-day living; hence, story and situation may occupy a less central place. Its role in a sexual health game is, in contrast, likely to be much more central, particularly if the game is for young adolescents who are learning to read and navigate situations of potential sexual risk for the first time: situation-based cognitive and behavioral rehearsal is essential to help them prepare. It is nonetheless notable that the structure of our Theoretical Framework, integrating intervention components, mediators, and outcomes, draws inspiration from that of Thompson et al [29] for a narrative-based game designed to prevent Type 2 diabetes and obesity among young people. In short, narrative has relevance whenever we are seeking to facilitate the transfer of behavioral skills to real life, whether it is choosing where to set limits on a first date or choosing wisely when ordering a meal at a restaurant.

There was for a time a contentious debate within the game literature about narrative-oriented versus game-oriented approaches (the "narratology vs ludology debate"). By way of conciliation, Ryan [63] differentiates between the *narrative game*, in which story is secondary to gameplay, and the *playable story*, in which gameplay is secondary to story. She relates this distinction to 2 forms of play: *ludus* (more rule-bound, competitive, and focused on problem-solving) and *paidia* (imaginative play, eg, make-believe). Unlike *ludus* games, *paidia* games do not lead to winning or losing. Driven by stories based on decision trees, *Tumaini* 's central structure is more aligned with *paidia* and the *playable story* than with *ludus* and the *narrative game*. It cannot be won or lost, and no strategic game-based thinking is involved.

PlayForward: Elm City Stories, a game for a similarly aged US minority population, has comparable HIV education and risk reduction goals. In contrast to *Tumaini*, however, *PlayForward* is a winnable game and would be situated more toward the *ludus /narrative game* end of Ryan's spectrum. In *PlayForward*, a set of mini-games are the primary vehicles for delivery of intervention content related to knowledge and skills. Each mini-game focuses on a specific set of behavioral or motivational outcomes. After successfully engaging with a series of stories representing risk situations teens face in middle and high school, players acquire "senses" and "powers" by playing the skills-based mini-games [64]. The People Sense mini-game, for example, is intended to increase adolescents' "knowledge about social dynamics, risk taking, and the interaction of social dynamics and risk taking." Here, players learn to navigate peer relationships by identifying peers who may be more likely to engage in risky behaviors. They manipulate the physical closeness of individuals to their own avatar to graphically represent a distancing of risk. *PlayForward* has been shown in RCT to improve knowledge and attitudes [65].

In contrast to *PlayForward* 's more cognitive model, *Tumaini* seeks to foster experiential and intuitive contextualized learning through its interactive narrative-based approach. The player observes peer pressure in action, makes decisions for the characters facing it, and follows the consequences. Older non-playable characters act as mentors and distill key messages from these experiences. The player is asked whether she/he has faced similar situations in real life ("What about you?") and to reflect on how they might react in these situations. The player then has an opportunity to practice skills in responding to peer pressure scenarios in a mini-game, in which she/he must select a response and is given feedback by 1 of the game characters acting as a virtual mentor. It is hoped that this will allow players to intuitively extract general rules and situational skills from the specific scenarios they are exposed to in the role-playing game (through multiple parallel but nonredundant examples) and apply them in their own lives. Repeat exposure to parallel situations should help build an experience-based, emotionally charged, and intuitive "gist" learning [50].

Interactive Narrative in Sexual Health Games

Sexual health interventions rooted in interactive narrative have been referred to by various names, depending on the extent of their narrative content and their medium (and hence technological affordances). In his 2011 review of computer technology-based interventions in HIV prevention, Noar identified "virtual decision-making interventions" as "interventions that simulate dating and sexual situations and allow the user to make choices at various decision points and witness the consequences of various (good and/or bad) decisions" [66]. In 2015, Muessig et al termed "Virtual Reality scenarios" those that are designed to "increase mastery of important skills...address affect management, and provide more robust situation-specific intervention techniques (eg, practicing

HIV status disclosure or condom negotiation skills)" [4]. Key examples of such interventions for our purposes are *Socially Optimized Learning in Virtual Environments(SOLVE)* [67] and *What Could You Do?* (subsequently updated and expanded into the interactive video-based intervention *Seventeen Days*) [68]. Both interventions were pioneering interactive interventions in the years before new digital media and have evolved with technological advances. Both interventions feature "virtual dates" in which the user makes choices for the characters that lead them toward or away from unsafe sex. However, where *SOLVE* is for men who have sex with men (MSM) and is now delivered via the Web, having been rebuilt for a game platform, *Seventeen Days* (and its precursor) is an interactive video for heterosexually active female teenagers and is designed for delivery in health clinics.

SOLVE invites MSM to participate in an interactive virtual environment designed to "simulate the emotional, interpersonal, and contextual narrative of an actual sexual encounter while challenging and changing MSM's more automatic patterns of risky responses" [69]. As participants role-play characters in socially engaging and emotionally realistic sexual situations, their learning is scaffolded by supportive, and often humorous, virtual peer counselors who provide advice and possible negotiation tactics. *SOLVE* counselors can "make clients' emotions, cognitions, goals, problem solving, and decision-making steps more salient, especially when these are leading to risky outcomes." Those who received the interactive video in addition to counseling reduced risky sex and increased protected sex compared with those who received counseling alone [69].

Although intended for a different audience, *Tumaini* bears some similarities to *SOLVE*, not least by virtue of its focus on *affect*. The player is asked not only to make choices at decision points faced by the virtual characters but also to identify with their emotional state through the "inner voice" ("How do I feel?"). It uses virtual mentors (sometimes referred to as "pedagogical agents") in the form of non-playable adult and peer characters to provide guidance in the role-playing game and to provide feedback on exercises in the mini-games. Where *SOLVE* focuses on self-regulation for sexual decision-making among MSM, our focus on a preadolescent, prerisk population meant that we placed greater emphasis on cognitive and behavioral rehearsal for situations our players had not yet encountered and related outcome expectancies. We are currently developing an iteration for older adolescents, in which this balance is likely to shift.

In addition to interactive vignettes, *Seventeen Days* includes a condom demonstration scene and "mini-documentaries." Based on formative research, the intervention was designed to address women's perceived lack of control over sexual situations. It sought to show teenage girls that sex is not something that just happens and that they have choices in sexually charged situations. In the initial RCT, the interactive *What Could You Do?* video increased reported abstinence and reduced reported condom failures and sexually transmitted infection diagnoses post intervention compared with 2 comparison groups [68]. In the subsequent RCT, participants in the *Seventeen Days* arm reported higher perceived condom acquisition self-efficacy after 6 months [70].

Built on the science of decision-making [3], *Seventeen Days*, like *Tumaini*, seeks to help adolescents develop proficiency in identifying and evaluating risk situations before their exposure to them. It is distinctive for the emphasis it places on cognitive rehearsal. At various points, the screen freezes for 30 seconds and the user is invited to mentally rehearse what she would do in this situation, for example, "What could you do if you didn't want to go off alone with a guy? Think about it, and practice it in your head." Downs et al [3] summarize their interactive narrative-based strategy:

> *We sought to create a mental model that afforded the active mastery needed to absorb future information and experiences, and to make inferences about unfamiliar situations...By helping viewers to identify choice points, analyze their impacts, and rehearse potential responses in advance, the intervention sought to empower young women to create their own, alternative, practiced scripts.*

As a prerisk prevention intervention for preadolescents, *Tumaini* as currently designed for a general 11- to 14-year-old audience does not explicitly invite cognitive rehearsal in sexually charged situations. However, it consistently seeks to link the virtual world with the real world. For example, in "What about you?" questions at the end of each chapter, the player is invited to relate events in the role-playing narratives, such as when a character is pressured by an older adult to have sex, to their own lives ("Who would you talk to if someone older than you tried to put pressure on you to have sex?"). Similarly, the *My Story* reflection and goal-setting components are coordinated with the content of the role-playing game such that during a chapter when a character wrestles with norms of masculinity, the player is invited to select values he/she has about what kind of man/woman he/she wants to be. More research is needed to better understand players' thought processes when making decisions in the role-playing game.

The player is not only invited to decide the actions of the character but also to choose between potential emotional states. For example, when Ruth finds out that a boy likes her, the player must decide whether she is feeling *Flattered*, *Nervous*, or *Excited* about the prospect. We believe this helps the player put him or herself in the shoes of the character and become emotionally immersed, leading to cognitive rehearsal on a direct, personal level. More research is needed to understand if the tendency observed in Green and Jenkins's research whereby readers of interactive narrative make the choices they would make in real life carries over to our preadolescent Kenyan participants.

Tumaini differs from *Seventeen Days* and from *SOLVE* by virtue of the extent and thematic scope of its interactive narrative format. Where the other interventions are based on vignettes, *Tumaini* has a full narrative structure. Each of *Tumaini* 's 18 chapters is devoted to 1 of the 6 characters. Although the characters represent a range of socioeconomic backgrounds, they all move within the same geographic universe, represented by a town with primary and secondary schools, restaurant, clinic, etc. In short, although *Tumaini* 's interactivity aligns with

SOLVE or *Seventeen Days*, its narrative structure is more akin to an entertainment-education soap opera [71].

PlayForward, *SOLVE*, and *Seventeen Days* were designed for US populations who have greater ease of access to interactive digital technologies than the population for which *Tumaini* was designed. There are, however, precedents for the use of interactive narrative for HIV prevention in sub-Saharan Africa. *Three and a Half Lives of Philip Wetu* is a 30-min interactive HIV prevention video made in Namibia that allows the audience to make choices for the male protagonist who has multiple concurrent female partners [72]. The interactive video is distinctive for being designed for facilitated use in a group setting. At the 3 decision points in the story, the audience is invited to discuss what has happened so far and decide what Philip Wetu should do next (eg, whether he should get tested). The film then continues in line with the audience's decision. *SwaziYolo*, in contrast, is an interactive smartphone game designed for individual use by young adults aged 18-29 years in Swaziland. In *SwaziYolo*, the player assumes the role of a young adult looking for love in Swaziland, making decisions about relationships and sexual health. The game consists of 2 parts—an imaginary social network and a series of dates in nightclubs and cafes. The player's choices between different potential courses of action affect his or her own health and safety and the opinions and behaviors of other characters; thus, the goal is to stay healthy and happy while maintaining relationships with other characters. *SwaziYolo* is currently being trialed in an RCT [73].

Theoretical Elaboration and Areas for Further Research

Within the humanities-focused literature, interactive digital narrative (IDN) has been described as extending "from avant-garde art to interactive documentaries, electronic literature, video game design, applications of artificial intelligence (AI) research and ubiquitous computing" [41]. Buoyed by the horizons opened by AI, scholars have suggested that IDN "bestows cocreative power on its users" and "promises to dissolve the division between active creator and passive audience and herald the advent of a new triadic relationship between creator, dynamic narrative artefact and audience-turned-participant" [41]. As technological possibilities have evolved, public health applications of interactive narrative have grown alongside artistic experimentation and the deployment of increasingly complex algorithmic possibilities.

With hundreds of decision points—many with consequences for the plot, a few, without—across its 18 chapters, *Tumaini* offers an extensive array of possible "instantiated narratives" [74]—and over 40 possible outcomes (represented by discrete epilogues) across the 6 characters. These narrative permutations, although extensive, are certainly not limitless as is envisaged by some AI-driven interactive narratives. Within applied uses of interactive narrative, the choices offered to players are likely to remain circumscribed in line with the game's learning objectives. It is nonetheless of value for public health to follow the evolving theory and practice of interactive narrative in other disciplines.

Given the importance of interactive narrative for skills-building through cognitive and behavioral rehearsal, development of outcome expectancies, and modeling, there is considerable need for further research in the field. Like the interventions described above, research on interactive narrative has covered a range of media and platforms, from written texts [40], through interactive television [43], to our own smartphone game. Although there is potential for cross-medium learning, there is also a need to differentiate between the respective effects of different platforms. Pressing areas for further research also include the need to better understand (1) players' mental processes while navigating and making decisions within an interactive narrative, including their motivations for choosing one path over another; (2) whether the perspective of the player (first vs third person) affects transportation and identification; and (3) the differential impact of different paths through the narrative and accompanying loss or gain frames [40].

Although Voderer et al [75] have suggested that interactive narratives are only beneficial to audiences with higher cognitive capacities, the quantitative and qualitative findings from our pilot study of *Tumaini* with very young adolescents (and the longstanding youth appeal of CYOA novels) suggest otherwise. In our pilot study, *Tumaini* functioned as a stand-alone intervention for preadolescents. However, we plan to bolster parent-child communication, social support, and linkage to services within a more extensive intervention package addressing a wider range of audiences within a socio-ecological framework.

Our Theoretical Framework separates psychological process mediators, drawn from communication theory, from behavioral outcome mediators, drawn from social behavioral theory. However, there is evidence of direct linkage between, for example, transportation and attitudes. In our 2017 pilot of *Tumaini* in Western Kenya, we did not measure the psychological process mediators identified in our Theoretical Framework because of concerns around response burden for our preadolescent participants. Various scales assessing these mediators are available for adaptation to our audience. Mediation analysis, facilitated by log files generated by our game, will allow us to better parse out linkages of these cross-disciplinary mediators and better understand the mechanisms of effect of our intervention. This will, in turn, increase understanding of processes of health behavior change and support the development of increasingly effective games for health interventions.

Conclusions

Calls for improved behavioral theories for mHealth interventions have arisen from the need to better describe process and effects of interactive, adaptive, and dynamic interventions at the intraindividual [14] and social levels [16]. Although it is unlikely that we will dispense with well-established behavioral mediators, there is an increasing need to build new theoretical frameworks drawing on literature informed by disciplines ranging from computer science through the cognitive and behavioral sciences to the social sciences and humanities.

The increasing availability of smartphones, including in low-income countries, offers unprecedented opportunities to take advantage of the potential for interactive narrative to contribute to health promotion efforts. We have shared the multidisciplinary theoretical framework that guides *Tumaini*, a smartphone-based HIV prevention game. The development and sharing of multidisciplinary theoretical frameworks, combined with studies incorporating multilevel mediation analyses, could contribute to the development of new theoretical frameworks to guide and explain the effects of games for health and other mHealth interventions and thereby increase their effectiveness.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Sample graphics from Tumaini.

[PDF File (Adobe PDF File), 699KB - games_v7i2e13037_app1.pdf]

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Abbreviations

AI: artificial intelligence
CYOA: choose-your-own-adventure
IDN: interactive digital narrative
mHealth: mobile health
MSM: men who have sex with men
RCT: randomized controlled trial
SCT: Social Cognitive Theory
SOLVE: Socially Optimized Learning in Virtual Environments

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Viewpoint

Affective Game Planning for Health Applications: Quantitative Extension of Gerontoludic Design Based on the Appraisal Theory of Stress and Coping

Najmeh Khalili-Mahani[1,2,3], MEng, MA, DPhil; Bob De Schutter[4], DPhil

[1]PERFORM Centre, Concordia University, Montreal, QC, Canada

[2]McGill Centre for Integrative Neuroscience, Montreal Neurological Institute, McGill University, Montreal, QC, Canada

[3]Department of Design and Computation Arts, Concordia University, Montreal, QC, Canada

[4]Armstrong Institute for Interactive Media Studies, Miami University, Oxford, OH, United States

Corresponding Author:
Najmeh Khalili-Mahani, MEng, MA, DPhil
PERFORM Centre
Concordia University
PC 2 207, 7200 Sherbrooke O
Montreal, QC, H4B 1R6
Canada
Phone: 1 514 848 2424 ext 5370
Email: najmeh.khalili-mahani@concordia.ca

Abstract

User retention is the first challenge in introducing any information and communication technologies (ICT) for health applications, particularly for seniors who are increasingly targeted as beneficiaries of such technologies. Interaction with digital technologies may be too stressful to older adults to guarantee their adoption in their routine selfcare. The second challenge, which also relates to adoption, is to supply empirical evidence that support the expectations of their beneficial outcomes. To address the first challenge, persuasive technologies such as serious games (SGs) are increasingly promoted as ludic approaches to deliver assistive care to older adults. However, there are no standards yet to assess the efficacy of different genres of games across populations, or compare and contrast variations in health outcomes arising from user interface design and user experience. For the past 3 decades, research has focused either on qualitative assessment of the appeal of digital games for seniors (by game designers) or on the quantitative evaluation of their clinical efficacy (by clinical researchers). The consensus is that interindividual differences play a key role in whether games can be useful or not for different individuals. Our challenge is to design SGs that retain their users long enough to sustain beneficial transfer effects. We propose to add a neuropsychological experimental framework (based on the appraisal theory of stress and coping) to a Gerontoludic design framework (that emphasizes designing positive and meaningful gaming experience over benefit-centric ones) in order to capture data to guide SG game development. Affective Game Planning for Health Applications (AGPHA) adds a model-driven mixed-methods experimental stage to a user-centered mechanics-dynamics-aesthetics game-design cycle. This intersectoral framework is inspired by latest trends in the fields of neuroimaging and neuroinformatics that grapple with similar challenges related to the psychobiological context of an individual's behaviors. AGPHA aims to bring users, designers, clinicians, and researchers together to generate a common data repository that consists of 4 components to define, design, evaluate, and document SGs. By unifying efforts under a standard approach, we will accelerate innovations in persuasive and efficacious ICTs for the aging population.

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KEYWORDS

games; user acceptance of health care; psychology; informatics; aging; adaptation; rehabilitation

Introduction

Background

The concept of *healthy aging*, the focus of the World Health Organization's work on aging between 2015 and 2030, has sparked a growing number of cross-disciplinary research and creation initiatives to take action across multiple sectors to develop strategies for enhancing the autonomy and the well-being of older populations. Among the solutions are the assistive and rehabilitation technologies for the aging population promoted under digital health strategies for remote screening, preventive interventions, or dyadic or machine-coached rehabilitation [1]. Yet, the acceptability and accessibility of these technologies remains a challenge that needs to be addressed, with attention to the complexity of social, economic, and individual contexts of the living experience of older adults [2].

In this position paper, we focus on the gamification of digital training and rehab activities (known as serious games [SG]), which aims to deliver cognitive, emotional, and physical enhancement or rehabilitation routines for older adults [3,4]. For any behavioral intervention to become effective, it must first be acceptable and adaptable to fit the daily routines of the individuals. However, for many older adults, especially those with lower technological literacy or reduced cognitive and physical abilities, the barrier of technological access may be too stressful to overcome. We introduce Affective Game Planning for Health Applications (AGPHA) as an experimental framework based on the appraisal theory of stress and coping to inform SG design and evaluation processes.

Affective game planning builds on the premise that gamification offers a simulated challenge and a corresponding reward system that will motivate users to engage in enjoyable and meaningful health-related activities via information and communication technologies (ICTs). Here, we (1) propose a unifying framework based on a neurobehavioral model of stress and adaptation to address the need for a generalizable empirical approach that accounts for physical and psychological differences in appraisal and adoption of SGs, (2) explain how this model ties to existing theoretical and practical approaches to SG design (namely self-determination and flow theories), with particular emphasis on the necessity of designing enjoyable computerized health applications, and (3) propose a data collection and documentation approach that will enable the field to accelerate research and development of effective and adaptive SGs across multiple applications.

The motivation for this proposal comes from the field of behavioral neuroimaging and methods that it uses to evaluate and document the emotional and cognitive correlates of physiological and environmental phenomena. An influential theory that could explain the psychobiological variations in adaptation and learning, is the appraisal theory of stress by Folkman and Lazarus [5]. In this paper, we propose that the appraisal theory can incorporate 2 dominant game-design theories, self-determination [6] and flow [7,8] and propose a user-centered approach that emphasizes ludic and meaningful experiences in the mechanics-dynamics-aesthetics (MDA) design cycle [9]. We aim to address 2 of the major shortcomings in the field of SG studies: accounting for the complexity of a user's game-playing experience and preferences [10]; and creating a standard empirical framework to assess the accessibility and efficacy of games that can benefit seniors' health [11,12].

History of Games for Health

SG is not a new concept, and promoting the use of digital technologies for improving the quality of cognitive and emotional wellness of older adults has a long history. In their 1976 report of computer use for elder program, Jaycox and Hicks remarked the potential of *game playing* as a use case for building an intergenerational bridge to utilize the new informatics technology for generating easily sharable hypertexts that older generations can use to share experience and knowledge with younger generations [13]. In 1983, Weisman reported the applicability of computer playing in the daily routines of frail elderly (including those with Parkinson disease, dementia, and visual impairment and an average age of 85 years) and showed that 50 of the house residents agreed to repeat play slower adapted versions of 4 games with different skill requirements such as hand-eye coordination (*Brick Out* and *Country Drive*), audiovisual processing and reaction time (*Ribbet*), and memory (*Hangman*) [14]. They remarked the potential for games to increase attention and interest in the players on the one hand and to assist as diagnostic instruments on the other [14]. In 1984, McGuire [15] reported a study to suggest that computer-gaming broke the sedentary routine of residents of nursing homes after he measured elevated moods in 16 adults (compared with 12 nonplaying controls) 8 weeks after they were given access to Atari 2600 games (*Bowling*, *Football*, *Breakout*, *Pac-Man*, and *Space Invaders*). In 1986, Hollander and Plummer [16] introduced 10 games with various cognitive enhancement components (reaction, eye-hand coordination, and memory) in a community house of adults with an average age of 84 years and showed that, in principle, older adults were receptive to the idea of playing games for improving perceptual-motor skills, cognitive abilities, and attention spans from playing various games. The 17 participants who completed 3 weeks of training considered *Trivia* game (questions from popular topics in history, literature, and sports) and a computer-based *Hangman* (a multiplayer computer game to make words with given characters) to be the most interesting of all because they challenged them to think [16]. In 1987, Riddick et al brought 2 upright game arcades to a senior citizens retirement home and introduced them to 2 nonviolent and nonspatial games, *Pac-Man* and *Donkey Kong*, which were slow paced but allowed for progressive skill development—measurable after 19 sessions of playing. They also quantified a significant increase in arousal and recorded the accounts of players explaining why they found playing to be an uplifting experience—despite the fact that the game-play duration and pleasure declined [17].

These historical citations foreground a growing body of similar contemporary work trying to acquire more refined empirical data to support the benefits of more refined digital playing for mental and physical health in older adults.

Quantitative Serious Game Research

Since a decade, quantitative evaluation of game benefits has returned to the forefront. Basak et al trained 20 seniors (mean age of 69 years) on the personal computer game *Rise of Nations* for a total of 23 hours over the course of 8 weeks and showed improvements in cognitive tests (eg, n-back or mental rotation) compared with the untrained controls [18], even showing evidence for game-related changes in neuroplasticity [19]. Peretz et al performed a randomized trial in 155 seniors and compared a personalized cognitive training protocol versus various computer games assumed to involve cognitive functions (eg, *Tetris*, Target practicing games, and memory games) and showed game-related improvements (albeit weaker than personalized training) in overall cognitive scores [20]. In 2013, an influential publication in the *Nature*, a study of 64 participants (age 65 years, SD 5) provided evidence that training with a multitasking custom game *(Neuroracer)* significantly improved the cognitive control, with effects remaining up to 6 months after the training, concomitant with an increase in the power of theta-band electroencephalogram signals in the medial prefrontal region, an area important for memory and executive control [21]. Toril et al's meta-analysis of all the literature between 1986 and 2013 revealed that video game training has a positive impact on cognition, albeit the effect size was moderated by factors such as age, personality, and experimental design [22]. However, in a recent (2017) randomized controlled study of *Lumosity* (nonaction cognitive training) versus *The Sims* (active control condition), they found that the control group (*Sims*) became less distracted and faster than the experimental group in performing cognitive tasks [23]. In an independent earlier study (2015), Rose et al demonstrated that simulation of 1-week life planning in the form of a game produced measurable improvements in real-life planning [24]. Overall, it seems that some specific cognitive benefits may be gained from specific elements designed in digital cognition-targeting games [25].

Beside cognitive domains, exercise games (exergames) have been proposed and empirically evaluated for their cognitive benefits, for instance, in older adults with neurological conditions [26], or physical benefits—in terms of improving balance and fall prevention [27-31]. Computer games have also been proposed for cardiac [32,33] and stroke rehabilitation [34]—subject of 3 Cochrane reviews, concluding on the insufficiency of statistical significance because of sampling heterogeneity and inconsistent reporting [35]. Beside quantifiable measures (cognition and physical fitness), which are still debatable [11,36], exercise games provide enjoyment and social interaction [37-44].

Primacy of Enjoyment in Seniors' Gaming

A recurring theme in studies that target older adults is that *enjoyment* trumps many challenges that would keep them from playing. A text analysis of the content of the literature concerning the older adult's game experience revealed that many items were related to the potential health benefits of playing digital games, with the top 10 of most recurring terms including *training*, *balance*, *physical*, *cognitive*, *exercise*, and *social* [9]. Despite the general assumptions about technological gaps, older adults, at least in Canada, are onboard for digital play [3]. A recent survey of over 880 older adults in Canada indicates that 73% of the respondents enjoy playing games because they provide social and cognitive stimulation [45]. In a massive online multiplayer game study (*World of Warcraft*), Zhang and Kaufman [46] demonstrated that interindividual variations in enjoyment of the social game experience remain an important determinant of benefiting from the game play experience. Ruvio et al have shown that the *fun factor* in video exercise games predicts adherence to exercise routine compared with the no-game condition [32]. Of course, enjoyment is not the only factor in determining the meaningfulness of a media-related experience [47,48], but in the context of older adults playing, it seems to be important [49]. Many argue that to provide pleasurable and enjoyable experience is the sufficient reason why computer gaming is *good* for older adults [3,48-51].

In the *Gerontoludic Manifesto* (2015), De Schutter and Vanden Abeele have argued that to advance the field of gaming for older adults, we must move away from the biomedical model of solving the problem of age-related decline but instead focus on how different types of games provide a positive experience for their players [52]. Subsequently, in *Gerontodulic Design* (2017), it was proposed that in designing games for older players, the initial step must account for game aesthetics (ie, the emotional response to the games) which reflect the personal essence of gameplay experience and that designers must start by creating enjoyable and playful interfaces that provide connectedness and meaning through implementation of the game mechanics (ie, rules, challenges, and rewards). In this framework, game planning involves gathering iterative player-centered empirical data from the game dynamics (ie, the phenomenology of experiencing the gameplay), as its mechanics evolve through aesthetic improvements [9].

A purely biomedical approach to the problem of design is too reductionist to account for the richness of diverse factors that shape the experience of an SG player, yet designers employ various quantitative approaches and rely on aggregating data through meta-analyses to create a formulaic recipe for enjoyable games that have a higher likelihood of uptake and retention by the players [9,50,53-60].

Theoretical Framework of Affective Game Planning for Health Applications

Motivation Theories That Inform Design for Seniors' Games

At the empirical level, *beneficial* game studies typically rely on well-established psychological motivational theories to understand who plays what, why, and how. In game studies, self-determination theory (SDT) of motivation [6] and flow theory [7,8] are dominant.

SDT posits that humans have an inherent need for autonomy and for developing competencies and relationships that will help them fulfill their goals for growth and self-actualization [6]. This theory is one of the most commonly applied in the field of game studies to explain relations between gaming and psychological need satisfaction [61-63]. The theory is also used as a framework to design gamified strategies for promotion of wellness [64]. Age-related variations in intrinsic and extrinsic motivations that underline SDT are important. In a meta-analysis of 11 independent studies, Birk et al aggregated 3041 samples of postgame player experience of need satisfaction (PENS) and intrinsic motivation inventory data and reported complex and age-dependent correlations between competence, relatedness, and intrinsic motivation [60]. Loos applied the SDT in examining the applicability of exercise games in older adults and found that although the exercise game satisfied the needs for autonomy and competence, they would not recommend the game to others; among the objections were the request for improved user interface or environmental background [65]. In fact, the issue of user interface and cognitive conditions in older adults is pertinent, especially because natural or pathological age-related decline in sensory, motor, and cognitive domains are expected to influence competence and need satisfaction [56,66].

The issues of interface and game accessibility are often addressed with the flow theory [7,8], according to which successful games must counterbalance their features along the axes of challenge and difficulty: if the level of challenge is too high and the player abilities are not commensurate, it leads to anxiety and discontinuation; if the level of challenge is lower than the abilities of the player, it leads to boredom and discontinuation. Nacke et al [67] examined the concept of flow in 2 groups of young and older healthy adults engaging in a pen-and-paper game versus a Nintendo puzzle game and tested the hypothesis that higher challenge associated with the Nintendo task would increase the flow and enjoyment of accomplishing the task. Using this method, they reported that although flow for older adults was correlated with challenge, positive affect, and arousal, for younger players, it was only correlated with challenge and that no affective correlations occurred in the younger sample. Belchior et al used the flow concept to compare the engagement of 45 older adults while training on a laboratory cognitive training stimulus versus training on commercial video games and reported significant increase in flow scores after 6 weeks of playing *Tetris*, as opposed to initially high but diminishing flow after 6 weeks of training on the laboratory game [68]. Marston et al showed different levels of flow experience in older adults trying different exergames, depending on which country the participants were recruited from [69].

Theory of Appraisal and Coping With Stress

Although SDT underlines the reflective component of playing motivation (competence, relatedness, and autonomy), the flow theory underlines the reflexive aspect (arousal, pleasure, frustration, and success). Our proposed theoretical framework unites these 2 by drawing on Selye's General Adaptation Syndrome (GAS) [70] and Lazarus' theory of coping, which incorporate motivational, relational, and cognitive components that give rise to individual differences in perception of, and coping with, stress, which is a physiological phenomenon linked to individual differences in biological factors such as metabolism, immune system, and adaptive learning (for an ontology by Lazarus, see [71]). This theoretical framework is supported by a wealth of evidence that enables us to investigate the interaction between biological and psychological factors that are known to impact not only the momentary experience of the game but also its learning and its long-term impact on broad range of health factors.

Biological Manifestation of Stress

Emotional experiences manifest immediate and quantifiable variations in physiological states [72] and cause reflexive embodied experiences (change in heart and breathing rate, galvanic skin response, pupil dilation, facial reflex, movement reflex, and gut reflex). In 1962, to illustrate the power of appraisal on triggering an affective physiological response, Lazarus used 2 silent films, 1 with emotionally charged content and 1 without, and showed significant autonomic responses to the emotive film in terms of heart rate and skin conductance [73]. A wealth of evidence has since accumulated to illustrate the role of this physiological response in enhancing arousal and preparation of the system for an initial *fight-or-flight* response (when the threat is immediate) or a latent *stress* response (when the immediacy of the threat has passed or the threat is of psychological nature) that impacts how one learns from *stressful* experiences [74-77].

In the context of the GAS, we define *stress* as a quantifiable physiological response to any anticipated or actual challenge, intrinsic or extrinsic, real or imaginary, threatening or exciting, that would require an organism to initiate an immediate autonomic response (in the alert/arousal phase) to meet the metabolic demands of extra physical or psychological efforts needed to bring the system back to its normal homeostasis (in the recovery phase) [78]. This physiological response is expected to be different between individuals and represents the sum total of increase on metabolic resources of the body to restore it to baseline, whether they are altered with actual illness or with distressing or joyful perceptions of external stimuli [79].

It is well known that prolonged exposure to stress chemicals can increase the risk of deleterious effects on several body organs, thus negatively affecting the healthy aging process [80]. However, acute stress is not an all-bad response [81] but an important factor for facilitating contextual learning [82,83], for example, through interactions with the reward-processing brain regions [84] or by shifting attention and focus depending on adaptive strategies of individuals [85] (thus, to develop slightly challenging games may serve as a cognition-enhancing activity).

Psychological Moderators of Stress

To reify Selye's biological reductionism, Lazarus proposed the transactional theory of stress and coping, postulating that appraisal and personality could enable one to use cognitive reasoning (recently referred to as mindfulness) to turn a bad stress response (distress and anxiety) to a good experience (eustress, learning, and acting) [5,71]. Lazarus and Folkman have long argued that differences in appraisal and coping strategies influence the dynamics of the GAS [86], and over 50 years of publications in the journal of Psychoneuroendocrinology are dedicated to providing empirical data to illustrate these differences. In general, novelty, unpredictability, and uncontrollability are stressful [87]. A meta-analytical study of over 200 experimental studies by Dickerson and Kemeney [88] provides compelling evidence that stress response is triggered upon perception of threat to the goal of self-preservation (both physical and social self). For instance, physical health is a self-preservation goal. If this goal is threatened by illness or expected surgery, then a stress response will follow. Similarly, if individuals are motivated to preserve their social self by keeping social status, esteem, and acceptance, then they will elicit a stress response (eg, to an exam or public speaking event which challenge this self-preservation goal).

Folkman and Lazarus [86] have suggested that when confronted with a challenging encounter, the primary appraisal process is to categorize it as irrelevant, benign-positive, or *stressful* depending on what implications it would have for their well-being. If the person has no investment in the outcome of the challenge, then they will have no need for it and will not commit to engaging with it. On the contrary, if they perceive immediate or potential benefits, they will experience positive affect. However, if they are not certain about this positive outcome (benign state), then they will enter the secondary appraisal stage, where the individual 'must do something about the challenge.' Therefore, the secondary appraisal focuses on the challenge: 'Is it feasible and within physical and cognitive abilities of the individual or not?'

The appraisal theory of stress postulates that primary and secondary appraisals of a novel challenge with respect to an individual's actual and perceived emotional and cognitive capabilities would modulate their motivation to approach (learn and play) or avoid the challenge.

As several studies of the playing preferences and patterns in older adults have shown (and we listed them above), they do not consider games to be threatening; however, they do evaluate the impact of games on their wellness by assessing them against their needs and projected benefits [3,48,50,53].

As SGs imply benefits (eg, improving cognitive, emotional, or physical health), then, in the primary appraisal process, they are not irrelevant but positive or benign. This is where the theory of appraisal overlaps the SDT in terms of challenging the user to satisfy their need for competence (Can they learn it?), autonomy (Do they want to learn it?), and connectedness (Does it link them to a greater community?). Next, if the individual decides to play, then the flow theory will apply, as they will ask questions such as: Is the challenge rewarding, arousing, and fun?

If the game is enjoyable and the challenge is not too difficult, then the user will experience flow, the appraisal becomes positive, and the user will keep playing until the self-determination and flow conditions are met. However, if it is too difficult, then the appraisal moves from positive to benign or even *stressful*, running against the individual's intrinsic need for self-determination and competence. In this secondary appraisal, personality and resources available to the individual will determine the coping process, broadly defined as (1) the ability to deal with functional demands, (2) creating motivation to meet those demands, and (3) maintaining a state of equilibrium that would allow to transfer skills and energy toward those demands [86].

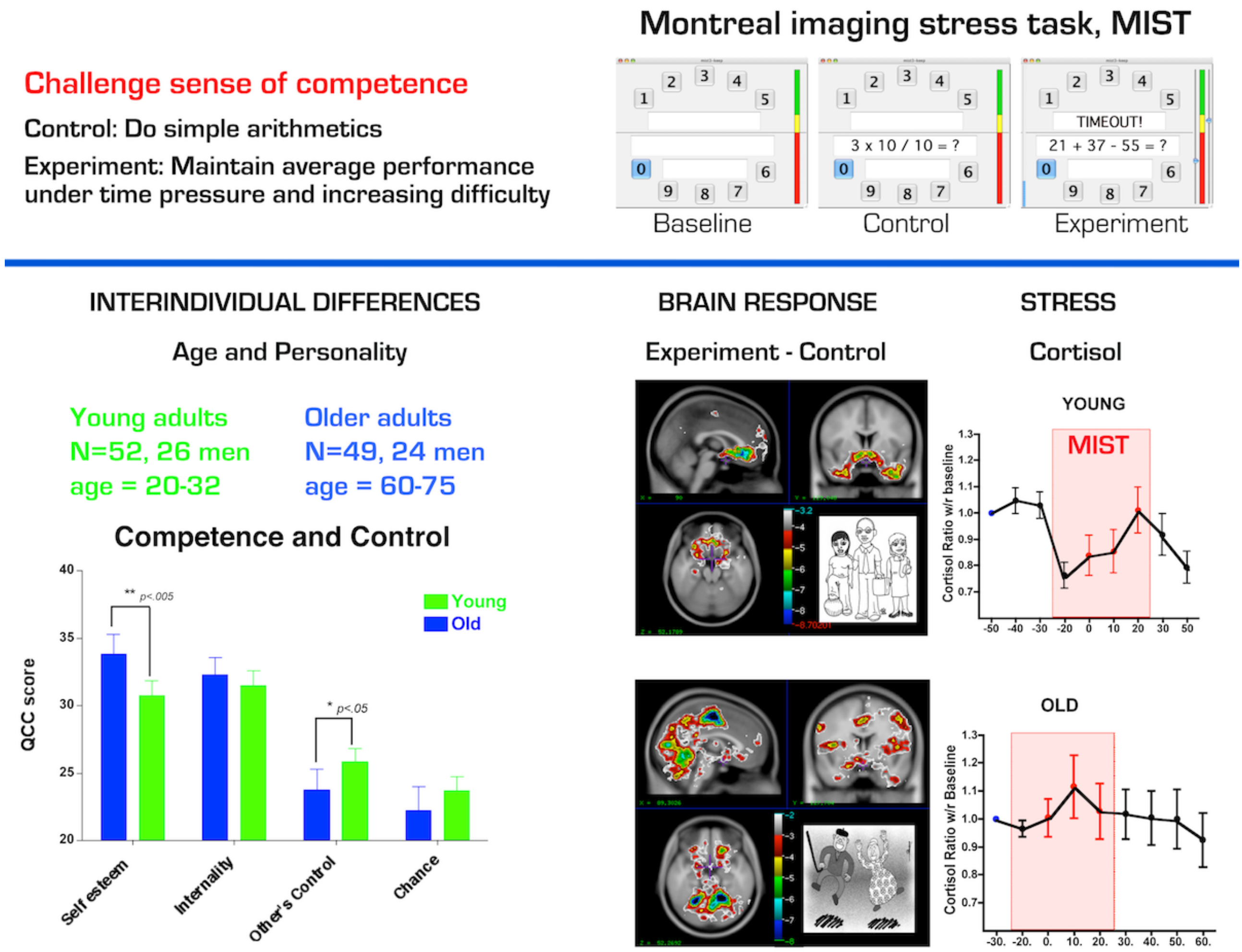
It is at the stage of coping with the challenges of a novel digital gaming experience that the individual will determine whether to turn the *stress* of the challenge into increased attention and practice or to give up and avoid the game stress after a few frustrating tries. According to Lazarus [86], this initial response adjustment is essential in forming later adaptive behaviors in relation to a given challenge. This is where the appraisal theory overlaps the flow theory in terms of arousal, pleasure, and frustration.

Neural Correlates of Appraisal in Testing a Game-Like Stressful Stimulus

As said before, stress is both a biological and a psychological phenomenon and differences in the appraisal of a challenge, together with behavioral coping traits, determine how one approaches or avoids them. Neuroimaging studies of reward, attention, and stress processing can help test transactional models of how a game will exert an immediate or long-term effect on the brain and the subsequent behavioral outcomes. An exhaustive review of this field is beyond the scope of this work, but we draw attention to one of our own observations of how intrinsic differences in perception or differences in cognitive reserves can manifest as distinguishable neuronal activation patterns. In a laboratory stress-simulation study in young healthy adults, we observed that individual differences in physiological stress response to a cognitive stimulus resulted in differences in activation of brain areas involved in learning and emotional processing [89]. We investigated this question in 2 age groups using a game-like mental arithmetic task [90]. This task involved performing simple arithmetic under time pressure, with a competitive element that implied competence if players maintained their performance above the average level. The task became increasingly more difficult if the players' scores reached the average—without their knowledge. The results are summarized in Figure 1. We observed that when compared with a control condition (performing mathematics without time pressure and without scoring), this task induced different patterns of stress response (measured from hormonal levels and brain activity) in the old and the young participants (with the young being significantly more stressed than the older participants) [91]. Although the young participants engaged the frontotemporal parts of the default mode network (involved in emotional control), the older participants engaged the parietooccipital parts (involved in executive function). This difference was also significant at the level of personality scores—with the young population having lower self-esteem and higher perception of lack of control. This example suggests that age-related differences in perception of the competition and competence or differences in cognitive and emotional reserves may have been linked to significant neurobiological differences.

Hypothetically, if this task was presented as an SG designed for activation of the prefrontal brain regions, then it would not be as effective on the older groups as it would be on the younger ones. Conversely, if this task was administered to increase activation of the posterior parietal regions, then it would be more effective in older adults than the younger ones. In other words, the transfer effects of gamified interventions would significantly vary depending on how players engaged with the game depending on appraisal and affective reaction to the game.

Figure 1. The summary of results from a neuroimaging experiment using a game-like task (MIST). We compared effects of doing metal arithmetics under time- and observer-pressure on brain and stress response in 2 groups of healthy young and older adults. Group differences in personality (Questionnaire of Competence and Control), brain activation (hemodynamic response to experimental versus control), and stress (cortisol) emerged, potentially because of differences in perception of the stressful nature of the task.



Experimental Framework of Affective Game Planning for Health Applications

Quantitative and Qualitative Outcomes

To provide empirical evidence for potential cognitive or health-related benefits appears to be a source of motivation for older adults to adopt computer games in their lives [52,92-95]. Empirical data are also necessary to make recommendations about which serious game to play, and how often [96]. Empirical methods to evaluate game benefits are often focused on evaluated on the expected outcome. In a 2012 review of SGs, Wiemeyer and Kliem [12] have listed a range of physiological functions that can be targeted with SGs, such as cardiovascular and cardiorespiratory system (eg, endurance, cardiovascular fitness, and prevention of cardiovascular diseases), energy metabolism (eg, weight control and prevention of obesity and diabetes mellitus), strength and flexibility (eg, posture and range of motion), bone structure (eg, prevention of osteoporosis), immune system (eg, prevention of cancer), and sensory –motor coordination (eg, reaction, balance, and fall prevention). Regardless of the outcome, the game interface mediates the perceptual experiences of activities that target a biological outcome; therefore, gaming is a primarily neuropsychological phenomenon. In other words, the game interface sits between the user's perception of and interactions with the game and its transferable health outcomes. Although many scientists acknowledge the potential for health SGs, they often neglect the primacy of emotional variables (such as stress, flow or aesthetic experience) in game-related studies of older adults. These issues are often tackled by human-computer-interface (HCI) designers, who emphasize consideration of user's cognitive and physical abilities that determine their experience and help them overcome challenges related to motivation and preferences [10,97], cultural contexts [53,98], affordance, control and self-determination [54,55,99-101], and accessibility [56,66]. We briefly propose two models that can be tested using a mixed methods approach.

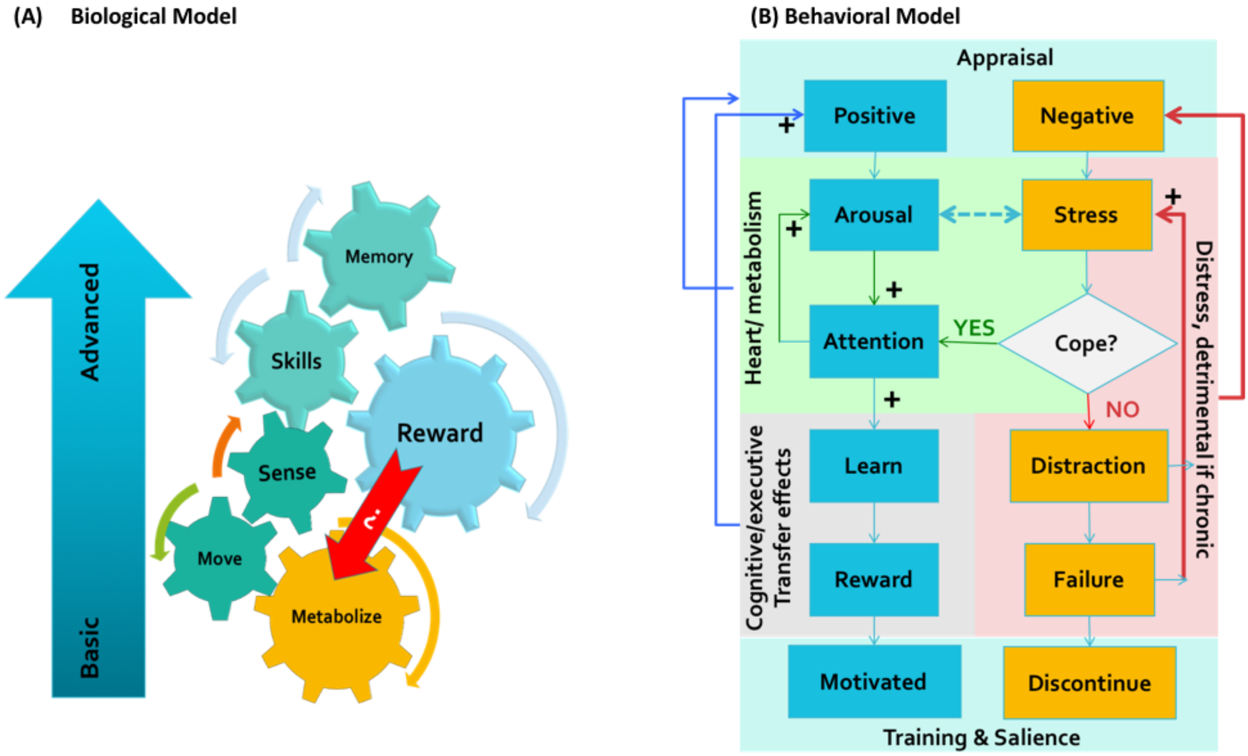
Biological Model

Consider the model in Figure 2 which illustrates a simplified model of the interrelations between the most basic elements of adaptation. Organisms, from the most basic to the most complex, evolve through an intricate chain of interactions that are tied to basic metabolic regulation of the internal milieu while surviving through a highly variable external milieu (the very bottom of Maslow's hierarchy of needs) [102]. Brain development involves a chain of interactions with the external world. They begin with sensory processing of the outside information that enters the body through the primary senses: vision, hearing and touch; and movement. Senses and movement further evolve as we grow (or decline as we age) by learning skills that support this process [103]. The genetic and neurochemical signaling pathways that support this learning process are tied to reward and fear processing, and the brain learns the world through an iterative evaluation of the situation and stimuli that are rewarding and enhance its well-being and avoiding or fighting those that threaten it [104-107]. These mechanisms create a closed-loop control system, any of which if broken will put the body in the state of allostatic load (or stress) [108,109]. The physiological manifestation of a stress response reflects the end product of myriad adaptive changes resulting from the interactions between the brain and other organs aimed at restoring the allostasis (ie, the ability to maintain stability through change). Neuroscientists argue that higher human functions, such as communication, creativity, empathy, and playfulness, are all manifestations of the humans extending this exploratory and interconnected terrain—sensing, moving, being rewarded, and learning [110,111]. Whether a game-playing experience produces a sum total of rewarding experiences or not will impact all elements of the system. Individual differences in movement, sensory processing, skills, and learning abilities will determine to what extent an activity is rewarding or stressful as well. We argue that in designing any SG for assistive health care, this big biological picture must be accounted for creating optimal flow experience. Considering that GAS affects the metabolic substrates of behavioral adaptation, the theory of appraisal fits the *big picture* by bridging between behavioral and biological factors that interact during a game-playing experience. For example, one might ask whether appraisal of the game reward will modify behavioral factors such as speed of execution of the game, and metabolic factors such as heart rate, and whether that will transfer to change in higher functions such as hedonic experiences, learning and memory.

Behavioral Model

Now consider another experimental model in Figure 2, a testable model of how game appraisal will predict later game-playing experience and adoption. The primary point of encounter between a user and a conceptual game is *appraisal* of the value of the exercise. If the game is solely presented as a source of entertainment, then it will have no stressful component, and the choice to play or not will depend on the player's personal and cultural preferences for pastime. However, if the game is presented in the context of mental or physical health or as a preventive lifestyle strategy, then it implies benefits. At the first encounter with this game, the user will either believe the promise of benefits or reject it as useless or impossible to do. If it is rejected, then they will not further engage in the process. However, if they do subscribe to the beneficial narrative, then the ability to play or not play will become attached to the notion of one's *self*, and from there on, the interaction with the game will depend on the individual's appraisal and coping processes with the physical and mental demands of learning and executing the game successfully. In this case, 2 scenarios can unfold that are described below.

Figure 2. A schematic model of how games can be evaluated based on (a) a biological model (b) or an experimental psychological model of game appraisal to predict its long-term effects.



Scenario 1: When the Game Becomes a Source of Distress

Having accepted the game as a potentially meaningful and health-beneficial activity, if the player perceives the game positively (eg, enjoyable and meaningful), then the player will feel aroused by the game and will pay attention to the gameplay. Games must be challenging to remain interesting, so the player must be challenged enough to fail as the game becomes more challenging. At this moment, secondary appraisal process will engage: "What should I do with the errors?" If the challenge is of value, then the player will increase attention and persevere to learn (eustress) [6,74-77]. If this perseverance results in improvements, then the gameplay becomes rewarding and the player will continue to play (in the state of flow). However, if increased arousal, attention, and practice do not produce positive results (ie, learning and improvement or meaningful connections to their personality or cultural context), then there is a chance that the player would become frustrated and revert to the first appraisal stage: "Is it impossible?"

Scenario 2: When the Game Becomes a Source of Eustress

Having accepted the game as a potentially meaningful and health-beneficial activity, if the player perceives the game negatively (eg, too difficult to learn and execute or meaningless to their interest or aesthetic taste), then the experience will become implicitly threatening to their sense of competence and self-efficacy. The player will construe their inability to understand, relate to, and execute the game as a potential source of health-related disadvantage. At this moment, the secondary appraisal process will engage: "What should I do with the fear of failing?" If the game is arousing (either because it is enjoyable or exciting), then the players will increase attention and persevere to learn it, thus turning the stressful context into a reinforcement for learning (eustress). However, if the game is not enjoyable, then each failure becomes a perpetual punishing stressor, a distraction that will block the player's ability to learn. If this state of frustration is not overcome, the avoidance adaptive mechanism will kick in and, to protect themselves from added distress, the player will abandon the play and seek alternatives.

Adding Science to Gerontoludic Design

Design Steps

AGPHA offers a scientific framework aimed at the development and evaluation of SGs on a wide range of effectiveness measures. A schematic diagram of the AGPHA is presented in Figure 3. AGPHA is a recursive mixed-methods evidence-based and user-centered process consisting of 4 elements: (1) defining the health-related problem that an SG is to address, (2) identifying or designing a ludic intervention (whether curated from existing games or new), (3) a standardized procedure for data collection during game evaluation or design, and (4) an archiving system that would allow tracking the evolution of the SG design and application over time.

The first step in the process is for scientists to identify the health domain that can be targeted using an interactive ICT, for example, telerehabilitation for stroke recovery, cognitive enhancement, emotional intervention, education, physical fitness, monitoring and data collection, diet and lifestyle, and social networking. As health-related interventions are inherently stressful, the primary aim is to identify or design game-like interfaces that motivate users to learn and sustain playing by minimizing the stressfulness of the activity and maximizing the enjoyment experienced from engaging in the playing.

For this reason, the SGs for health can benefit from a Gerontoludic extension to MDA, which consists of recursive evaluation of the following components:

Aesthetics

Typically, the starting point of MDA is for designers to identify emotional outcomes (ie, *aesthetics*) that players will experience as a result of playing a digital game. Considering that the deliverables of AGPHA projects require serious goals or health outcomes, designers and scientists must work together to define general game aesthetics (eg, challenge, fantasy, and competition) in relation to general preferences of older adults (eg, desire for connectedness, meaning, and competence).

Dynamics

After defining the initial aesthetics, designers must envision and design a dynamic system that will elicit the game's intended outcomes. At this stage, design prototypes or existing similar games will be tried to acquire a wide array of subjective and objective game experience measures that can be used to predict whether the game is likely to be enjoyable and effective or too stressful and inaccessible—in which case, the designers go back to reworking the aesthetics.

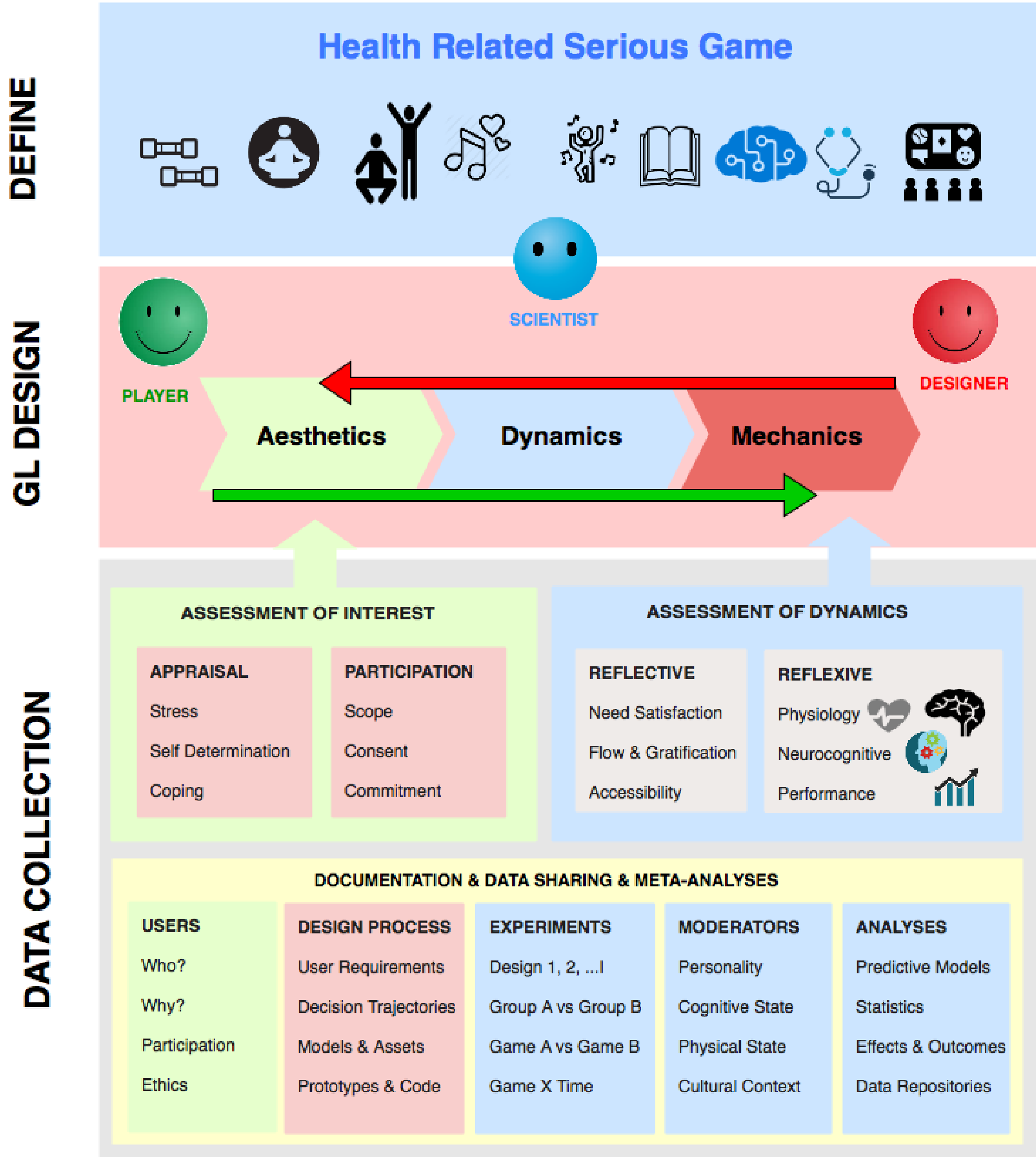
Mechanics

Finally, when a game's aesthetics and dynamics have been defined, designers can develop the actual mechanics of the game, that is, the rules and components that will elicit the intended dynamics. Again, at this stage, there is a need to evaluate the dynamics of game play and how they change with variations to the rules (eg, speed, challenge, and duration of play). At this stage, the designers and scientists must work closely with users to ensure that both health-related requirements and user requirements for aesthetics and accessibility of the game are met.

Data Collection

Figure 3 illustrates the scope of data that need to be collected in the AGPHA framework. AGPHA is an iterative mixed-methods approach to user-centered, evidence-based game design. It relies on the evaluation of the reflective (interests) and reflexive (experience) response to games that are developed through the MDA cycle. AGPHA relies on iterative testing and continuous documentation of the process of design and SG evaluation, with a common data thread to enable future aggregate studies.

Figure 3. The stages and scope of data collection in the Affective Game Planning for Health Applications framework.



Assessment of Interests

In the AGPHA framework, the first priority is to define the Gerontoludic aesthetics, through appraisal of a conceptual SG, by addressing questions such as: *Does the user believe the promise of the SG benefits, or reject it as useless? If they believe the health promise, then does it fit their value system? Does it make them feel connected? Does it satisfy their need for competence and self-efficacy? Are they willing to try it?Do they consent to collecting data from their game playing experience?* The second stage of appraisal begins only if the players have not rejected it right after the first encounter. From then on, the process of interaction with the game will depend on the individual's secondary appraisal (of the game dynamics) and coping processes. For health-related ICTs to be effective in the older population, they must rely on extensive qualitative studies that evaluate the design aesthetics in the presence of variations in personality and socioeconomic and cultural factors [4,112]. Thus, AGPHA heavily relies on focus groups and on the willingness and consent of the participants to commit to providing multiple quantitative data in the process of co-designing or testing a game. Therefore, experiments in this framework must be designed with regard to ethical considerations of an individual's privacy, their scope of consent, and the life cycle of the data.

Assessment of Dynamics

Game dynamics can be assessed both subjectively and objectively.

The reflective and subjective evaluation of game dynamics can be iteratively recorded using standard questionnaires such as The Player Experience of Need Satisfaction (PENS) that account for various elements of SDT such as competence, autonomy, control, and relatedness [61], or Game Engagement Questionnaire, which measures flow, presence, and immersion [113]), or a more recent aggregated questionnaire that incorporates the two [114]. We also recommend formulating specific questionnaires based on the characteristics of the game's mechanics (specific skills needed to play the game, content, movement of game elements, and medium on which the game is played), dynamics (game interactions, rewards, speed, flow, and game progression), and aesthetics (how one feels about the game and how it matches their expectations, values, and sensations) [9].

The reflexive and objective response to games can be recoded using physiological signals, which have long served as *biomarkers* of the phenomenological experience of stress in films [115-118] or video games [119]. Measuring physiological responses as a proxy for emotional and hedonic experiences during media consumption has served as a complement to cognitive evaluations or subjective evaluation methods, even in games. In a repeated-measures study of 19 young game players, Poels et al [120] compared 4 different games by examining the predictive value of physiological measures (facial electromyograms and skin conductance as proxies of positive/negative affect and arousal, respectively) in determining the likelihood of repeated and long-term game play. Van Reekum et al [121] measured electrodermal conductivity, forearm electromyograms, and heart interbeat intervals in 33 adolescents playing an action video game and showed an inverse correlation between the magnitude of physiological responses and performance. Mandryk and Atkins [122] used physiological metrics, such as galvanic skin response, facial electromyograms, and cardiovascular responses, and proposed a machine learning algorithm to dynamically compute the degrees of valence and arousal during a game play session in 24 young gamers and showed high convergence between the subjective ratings of games and the machine-predicted levels of emotion and arousal. Hébert et al showed that adding music to the experience of videogame playing caused a moderate increase in the levels of cortisol but no effect on performance metrics [123]. However, to the best of our knowledge, such experiments have not been done in older adults.

One reason for scarcity of such evidence in older adult studies is methodological complexity. Physiological data collection is often a cumbersome activity that requires laboratory protocols to ensure precision and consistency in timing the experiment and recording the experimental events. In addition, the measurement instruments, sensor probes fixed on the surface of the chest, face, or hand skin, are obstructive and extremely sensitive to movement artifacts, making them difficult to apply in a naturalistic gaming experience, especially for older adults. In recent years, neuroimaging methods have also opened an indispensable window into the evaluation of long-term neural benefits or harms of video games [19,21,124-126]. However, these methods are exorbitantly expensive and methodologically demanding, both for researchers and participants; therefore, incorporating such strategies in user-centered design would be impractical.

Recent years have witnessed an exponential growth in the availability of body-worn devices for continuous ambulatory monitoring and reliable wireless data transfer protocols that simplify the experimental setup and reduce the physical and psychological burden on participants. Therefore, opportunities for exploring the relation between reflexive and reflective experience of games in older adults are growing.

Beside physiological signals, several neurocognitive functions, such as short-term memory, reaction time, and attention, are susceptible to stress (eg, Stroop test [127] or short-term memory encode-recall tasks [128,129]). In addition, if the game can be scored easily and consistently, the play scores will supply a quantitative metric of performance. In addition, the long-term transfer effects of games can be measured on different cognitive domains, such as memory, reasoning, or visual speed processing [130].

Users

Factors in Serious Game Evaluation

Game users cannot be assumed as a monolithic population [10]. Identifying those who do or do not participate in game-design process, or make themselves available to extensive quantitative or longitudinal research, matters. Preferably, anyone who is targeted for SGs must be interviewed to some extent (even if brief) to document their motivation for joining or discarding the research or creation process that is proposed by researchers or designers. The number of individuals who volunteer to participate in study versus those who do not show interest or drop out in the middle is often an important indicator of whether a particular intervention is likely to be useful and adopted. Brox et al [55] and Gerling et al [66] have demonstrated the value of such qualitative data collection over long-term engagement of users in informing the design of senior SGs.

Games

Digital games are complex machines that come about through a long, expensive, and iterative decision-making process through collaborations between users, designers, and developers who, in the case of SGs, are guided by the expected health outcome of using the product. Khaled et al have recently outlined the necessity of documentation of the trajectories of the game design process, which revolve around dynamic decision making in confrontation between technological limitations, and human factors [131]. Proper documentation of the software engineering process is equally important, especially in developing health games, where the decision-making process must include expert requirements set by health care professionals [132]. The same factors can be documented when games are selected from existing commercial options (such as Kinect or Wii). Commercial games often have options to customize the interface aesthetics and game mechanics (eg, levels of difficulty) and may provide options to collect performance data.

Experiments

Depending on the research question, experimental designs aim to compare different games, different populations, and postgame effects with baseline or longitudinal game effects. However, a common thread running through different experimental designs will make the data amenable to post hoc and meta-analysis [12]. A need for open and standard game play metrics is increasingly acknowledged [133]. The appraisal theory provides a unifying framework that can readily build on a wealth of existing data from the HCI field (accounting for self-determination, flow, use, and gratification and arousal) and generate common data archives from independent but collaborative research by using common metrics and techniques from stress research (See Multimedia Appendix 1).

Moderators

The appraisal theory of stress heavily emphasizes the importance of trait factors and interindividual differences in physical and mental coping resources that shape an individual's approach to a novel challenge (eg, SGs) and predict their physiological and behavioral outcomes of engaging with the challenge over time. Factors such as general self-efficacy, self-esteem, and personality, as well as factors such as socioeconomic status; literacy; mental and physical health; and depression, anxiety or vitality scores, are important variables for which to account—both in statistical analyses and in modeling studies that evaluate the efficacy of games across different experimental conditions—in documents that keep track of the decision-making process in game design or game curation.

Analyses

Behavioral studies that account for affective aspects of phenomenological experiences are difficult to replicate, and this is one of the reasons why meta-analytical studies of SG efficacy, even when used to provide physical interventions using exergames, remain inconclusive about which regime and what dose of intervention is more effective [11,12,27]. To remedy this, it is important to clearly document analytical models that are tested on the data and to aim for replicable parsimonious models that provide easily interpretable results about the effect size of a given intervention on an objective and quantifiable metric. Furthermore, physiological data from biosensors are often metricized using postprocessing and data-reduction algorithms, which need to be described to maximize replicability in future studied.

Data Sharing and Documentation

To promote SGs for health application in a large scale or to adopt them in clinical rehabilitation routines, researchers must establish their efficacy first. The process of arriving at ideal SG is long, expensive, and often tested in relatively small samples. Given the complexity of cognitive, emotional, and cultural factors that give rise to game aesthetics and the heterogeneity of physical and mental resources that predict the targeted efficacy of game dynamics, it is not possible to make claims about the generalizability of the benefits of SG across different populations (eg, different genders, different ethnicities, and different countries) However, one might hope that adopting a standard framework to trace the evolution of SG development or validation across heterogeneous population or across different aesthetic choices will provide a tremendous opportunity for designing more adaptive and customizable games. AGPHA proposes to ground experimental design based on the appraisal theory of stress and carefully document and consider variations that arise from the following factors:

Future SGs can incorporate data from wearable self-monitoring devices, benefit from ubiquitous computing, and immerse users in customizable aesthetics of virtual and augmented realities. Thus, there is a promising potential for SGs at the heart of persuasive digital health technologies [4]. However, the field is young and in search of methods to establish the clinical relevance and efficacy of these emerging technologies. We draw the attention of health game scholars to research and developments in the field of functional neuroimaging that since 30 years ago have gathered a vast array of techniques and data to examine the link between behavior and neurobiology. Currently, the neuroimaging field has started to concert efforts toward the development of open-source tools and open-data repositories with 2 main objectives: (1) to perform collaborative longitudinal cohort studies to collect large amount of data from different populations using a standardized protocol [134] and (2) to aggregate data from diverse experiments to investigate a common dimension shared by various studies (eg, brain plasticity) [135]. Toward this aim, the AGPHA framework can readily take advantage of several existing platforms such as LORIS [136] and REDCap [137] designed to facilitate data storage for longitudinal and multicenter neurobehavioral studies. These studies have well-established ethical guidelines for lifespan neuroscience studies that may trace an individual in the course of their brain development or aging. Adopting similar standards for data collection, annotation, and documentation ensures adherence to strict policies regarding safety, privacy, and data security of human participants in clinical studies. Such repositories are likely to better inform the design and implementation of SGs based on information gleaned from model-free data mining and machine learning studies on data archives.

Conclusion and Future Directions

As gamified interventions for health become more *serious*, the need to extend the scope of participatory design to incorporate interdisciplinary, intercultural, and intergenerational concerns grows. Creating empirical and objective frameworks that bring designers, scientists, and technologists together will accelerate development of user-friendly and beneficial digital health strategies for seniors. We have proposed to take advantage of the appraisal theory of stress and coping as a generalizable and unifying framework for evaluation of the efficacy of health SGs. As the appraisal theory encompasses many elements of SDT and flow theory that are prevalent in current game studies, this approach is not a drastic deviation from existing practices. We have shown how this theory can be integrated in the Gerontoludic extension of the MDA design cycle. We also suggest to address the validation requirements of health efficacy of SGs and to draw on resources from neuroimaging and data science to concert efforts in developing adaptive games that address the individual's needs with regard to their physical, cognitive, and emotional resources.

Ultimately, if the SG research and development community reaches a consensus on how to create longitudinal data repositories in which various aspects of SG research and development can be archived, then we may hope to overcome the problem of small sample sizes and heterogeneity of experimental design that currently limit the scope of proving the clinical effectiveness of SGs. Hopefully, such converging efforts will also lead to developing more persuasive, *intelligent*, and effective SGs that can be tailored to the needs of individuals who need to play them for health benefits.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

List of possible instruments that can be used in data collection for Affective Game Planning for Health Applications.

[DOCX File, 38KB - games_v7i2e13303_app1.docx]

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Abbreviations

AGPHA: Affective Game Planning for Health Applications
GAS: general adaptation syndrome
HCI: human-computer-interface
ICT: information and communication technologies
MDA: mechanics-dynamics-aesthetics
PENS: Player Experience of Need Satisfaction
SDT: Self-Determination Theory
SG: serious games

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Viewpoint

Do-It-Yourself Gamified Cognitive Training: Viewpoint

Sjors CF van de Weijer[1*], BSc, MSc; Mark L Kuijf[1*], BSc, MSc, PhD, MD; Nienke M de Vries[2*], BSc, MSc, PhD; Bastiaan R Bloem[2*], BSc, MSc, PhD, MD; Annelien A Duits[3*], BSc, MSc, PhD

[1]Department of Neurology, Maastricht University Medical Center, Maastricht, Netherlands
[2]Donders Institute for Brain, Cognition and Behaviour, Department of Neurology, Radboud University Medical Center, Nijmegen, Netherlands
[3]Department of Psychiatry and Psychology, Maastricht University Medical Center, Maastricht, Netherlands
[*]all authors contributed equally

Corresponding Author:
Sjors CF van de Weijer, BSc, MSc
Department of Neurology
Maastricht University Medical Center
Oxford Building
P Debyelaan 25
Maastricht, 6229 HX
Netherlands
Phone: 31 626856672
Fax: 31 43 387 70 55
Email: sjors.vande.weijer@mumc.nl

Abstract

Cognitive decline is an important nonmotor symptom in Parkinson disease (PD). Unfortunately, very few treatment options are available. Recent research pointed to small positive effects of nonpharmacological cognitive training in PD. Most of these trainings are performed under supervision and solely computerized versions of (traditional) paper-pencil cognitive training programs, lacking rewarding gamification stimulants that could help to promote adherence. By describing 3 different self-invented ways of cognitive gaming in patients with PD, we aimed to raise awareness for the potential of gamified cognitive training in PD patients. In addition, we hoped to inspire the readers with our case descriptions, highlighting the importance of both personalization and cocreation in the development of games for health. In this viewpoint, we have presented 3 PD patients with different ages, with different disease stages, and from various backgrounds, who all used self-invented cognitive training, including elements of personalization and gamification. To indicate generalization into a larger PD population, the recruitment results from a recent cognitive game trial are added. The presented cases show similarities in terms of awareness of their cognitive decline and the ways this process could potentially be counteracted, by looking for tools to train their cognition. On the basis of the response of the recruitment procedure, there seems to be interest in gamified cognitive training in a larger PD population too. Gamification may add to traditional therapies in terms of personalization and adherence. Positive results have already been found with gamified trainings in other populations, and the cases described here suggest that PD is also an attractive area to develop and test gamified cognitive trainings. However, no results of gamified cognitive trainings in PD have been published to date. This suggests an unmet need in this area and may justify the development of gamified cognitive training and its evaluation, for which our considerations can be used.

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KEYWORDS

cognitive remediation; Parkinson disease; video games

Introduction

Background

Parkinson disease (PD) is a neurodegenerative disorder characterized by both motor and nonmotor symptoms. Mild cognitive impairment can already be present in up to 40% of newly diagnosed PD patients [1] and more marked decline can ultimately be seen in up to 83% of patients [2]. Cognitive impairment is associated with a decreased quality of life, an increased caregiver burden, and an increased risk of developing dementia [3]. Unfortunately, very few treatment options are available. The only effective pharmacological treatment (rivastigmine) provides limited improvements in memory and language [4]. Recent research has pointed to small positive effects of nonpharmacological cognitive trainings on working memory, processing speed, and executive function [5-7], suggesting that these interventions could possibly attenuate cognitive deficits in PD. Many of the investigated cognitive trainings in PD are performed under supervision and include solely computerized versions of paper-pencil (traditional) cognitive trainings. These traditional cognitive trainings involve repetitive execution of cognitive tasks but lack gamification stimulants. Gamification of cognitive training can be used to promote adherence, such as reward and engagement, and could eventually improve health outcomes. Both personalization and gamification could increase the adherence to and effectiveness of cognitive training in PD. Although some previously investigated interventions adapted to the user performance, adherence variables were unfortunately insufficiently reported across these studies. Therefore, we are currently unable to conclude that gamification of cognitive training is indeed more attractive for PD patients and results in increased adherence rates. Hence, more research is needed in the area of gamified cognitive training. Before we can test the effectiveness of such gamified cognitive trainings, it would be helpful to explore whether PD patients are interested in using gamified cognitive trainings at all.

Objectives

In this viewpoint, we have presented 3 independent histories of PD patients with different ages, with different disease stages, and from various backgrounds, who all used self-invented cognitive training that included elements of personalization and gamification. Using computer videogames, card games, or real-life routines, these patients self-trained their cognitive abilities, which are essential for activities of daily living. We will discuss the training types and present the similarities and differences between these cases. We additionally report on recruitment data from a recent gamified cognitive training trial [8]. By describing 3 different self-invented ways of cognitive gaming in patients with PD, we aimed to raise awareness for the potential of gamified cognitive training in PD patients. In addition, we hoped to inspire the readers with our case descriptions, highlighting the importance of both personalization and cocreation in the development of games for health. Finally, we have presented some considerations for future gamified cognitive training development and evaluation.

Cases

Case 1

This 64-year-old man with PD had a disease duration of 20 years and a Hoehn and Yahr Stage of III, indicating a mild-to-moderate bilateral disease and some postural instability but being physically independent (the range according to the Hoehn and Yahr stages is from 0 [no symptoms] to V [severely disabled and wheelchair bound]) [9]. In the course of his disease, he started experiencing postural instability, decreased memory performance, and depressive symptoms. His passion was virtual car racing, and he customized a computer videogame racing simulator (called iRacing, by iRacing.com Motorsport Simulations) with a trajectory on the Nürburgring Nordschleife circuit (Germany; see Figure 1 and Multimedia Appendix 1). At the time, he was treated with a levodopa equivalent daily dose of 1285 mg, including a daily dose of 3 mg Ropinirole dopamine agonist. He started racing on a daily basis in his simulator and challenged himself to improve on every race lap. He assessed his performance by remembering the influence of variances in turns on lap times. A race simulator challenges various cognitive functions (attention, decision making, and memory) as well as motor functions (reaction times and perceptuomotor skills). In the following months, he experienced improved driving skills in real life and better attentional performance while driving a real car, outside of the simulator. The patient's spouse believed her partner had an extended attentional span after playing the game regularly. His compliance was excellent, as the pursuit of the perfect race lap on the circuit was an intrinsic motivation for creating a gamified cognitive training task. He feels that pushing the boundaries prevents a rapid cognitive decline, and he has now faithfully used his simulator for over 5 years.

Figure 1. Screenshot of the racing simulator game played by Case 1.

Case 2

The second case is a 67-year-old woman with PD in Hoehn and Yahr Stage II (bilateral involvement without impairment of balance) and a disease duration of 12 years. Soon after retiring as a financial consultant in the field of education, she became afraid that the decreased working load on her brain would result in memory loss. A few years into the disease, she indeed started experiencing memory loss, which motivated her to train herself in daily real-life situations. Specifically, she has developed several daily routines to train her memory. After waking up, she tries to remember all meetings for the upcoming day. She, afterward, checks her calendar to see if she was right. Also, if she is outdoors and plans a new meeting with a friend, she will note it in her calendar only by the time she comes home. Afterward, she will check to see if she remembered the correct date and time. Also, she manually enters frequently used phone numbers, even though she has saved them as contacts in her smartphone. Furthermore, when she plans on shopping for groceries, she makes a shopping list on paper that includes all the needed ingredients. In the store, however, she will not consult this list, but instead she will buy all products from memory. The shopping list is ultimately referred to as a checklist for completion. This type of real-life training requires multiple cognitive functions, including planning and memory. The patient feels that these self-invented routines keep her memory stable at an acceptable level. She is now confident that she is able to remember almost anything, and she has never heard from others that she forgot something. Importantly, compliance was again excellent, as she has been using these daily routines for over 5 years now.

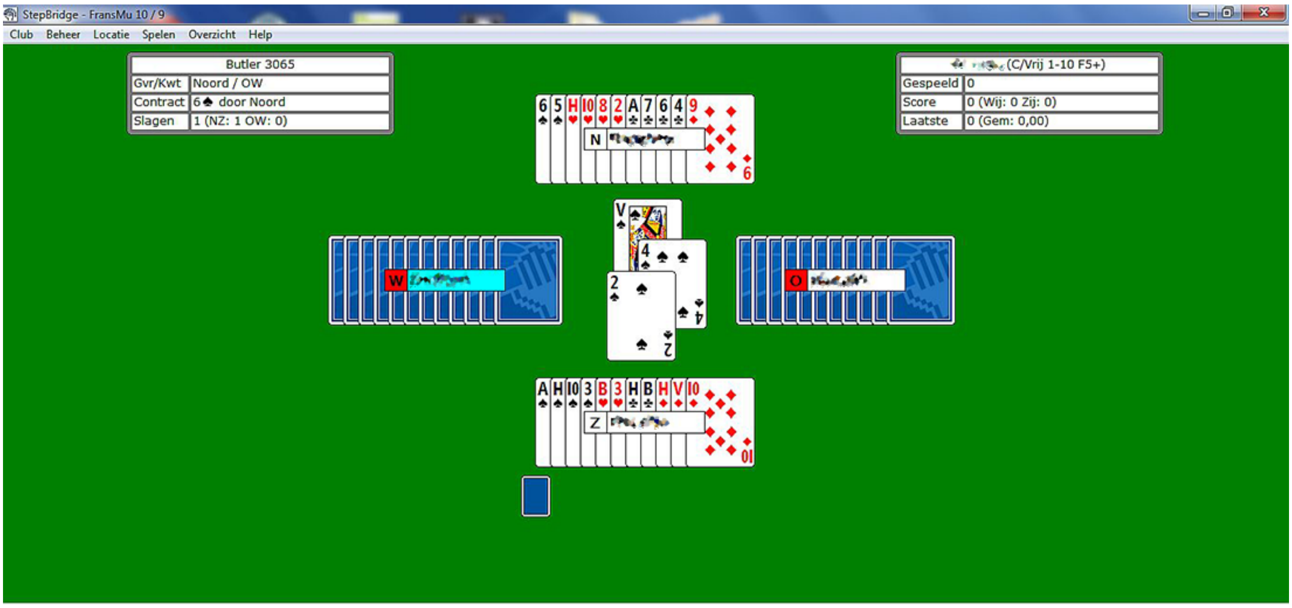
Case 3

The third case is a 68-year-old woman with PD in Hoehn and Yahr Stage III and a disease duration of 10 years. She has been living in South Africa volunteering as a community development worker for 28 years and has raised 5 children. After returning to the Netherlands, she was diagnosed with PD in 2009. In the following years, she started noticing cognitive problems, including concentration and memory deficits. She applied to a Dutch Web-based Bridge game service (called StepBridge, by StepBridge Foundation, see Figure 2), where she could play Bridge against gamers of similar difficulty levels at any time this would fit her schedule. This Bridge game requires several cognitive functions, including attention, reasoning, decision making, and memory. She reports subjective benefits in terms of both concentration and memory, which is also observed by her spouse. Compliance was again outstanding, as she has been playing StepBridge regularly for almost 10 years now.

Generalization of These Cases

To investigate whether this interest for gamified cognitive training can be generalized to a larger PD population, a recruitment newsletter was sent out which contained information on various PD research projects. Among others, it presented a brief introduction to a randomized controlled trial on the effects of a gamified cognitive training in PD [8], including 2 clickable buttons directed to the recruitment website. The newsletter was sent on April 3, 2017 at 7 pm to 1103 PD patients in the Netherlands. As early as the next morning, 60 patients requested the patient information brochure via the recruitment website. The email was opened by over 800 patients, and the recruitment website traffic increased by over 7 times within a month. In total, 135 PD patients requested the patient information brochure via this single newsletter and 55 patients applied to the study, underlining that a larger population of PD patients may be interested in using structured and gamified ways to train cognition. The results from this study are now being analyzed and, when published, may add to the current evidence for the effectivity of gamified cognitive training.

Figure 2. Screenshot of the StepBridge game played by Case 3.



Discussion

Principal Findings

The 3 patients presented here are, despite their differences in key characteristics such as age, gender, disease status, and disease duration, also similar in many ways. First, all 3 patients were aware of their decreased cognitive abilities and were proactively looking for ways to potentially counteract their imminent cognitive decline. They challenged themselves with self-invented trainings to improve their own daily life functioning. The first patient used a computer videogame race simulation to train his real-life driving skills. The second patient does not rely on lists to remember meetings or phone numbers, and thereby trains her memory performance for a variety of everyday functions such as shopping. The third patient used an online bridge game to train her concentration and memory performance. Taken together, these 3 stories carefully suggest that at least some PD patients are trying to counteract their cognitive deficits with self-invented trainings that address various cognitive skills. Whether such interventions are actually effective requires further formal testing in controlled studies.

Second, all 3 patients incorporated a form of play to address their cognitive deficits. Although the second patient did not resort to a game, the self-invented training approaches of all 3 patients entailed gamified elements (goals, challenges, and reward systems), which likely add motivation to continue the training. The first patient challenges himself to drive faster and faster laps, the second patient is rewarded each time she remembers the grocery list correctly, and the third patient has the goal to win as many tricks as possible. Indeed, in various studies, gamification has been found to increase the motivation and engagement of study subjects [10-12]. Owing to the predictability and repeatability of traditional (nongamified) trainings, eventually patients might get bored, increasing the risk of dropouts [13,14]. This could be avoided by challenging patients into performing interventions of varying complexity using attractive, interactive environments. There is debate on the support for gamified training and a large percentage of the general elderly population has never played game interventions [15], but it is unclear whether this is due to a lack of interest or if they are unfamiliar with the concept of gamified training. In exergaming studies, in the field of PD, it has already been established that patients are able to play games, improve their gameplay performance, and, more importantly, enjoy playing exergames [16,17]. One specific example was a recent study where gaming elements were used to promote adherence to a home-based exercise intervention; the results showed that PD patients, despite their well-known difficulties to engage in exercise, faithfully adhered to a regime of aerobic exercise at home, precisely as prescribed, namely 3 times a week for 30 min [18]. Also, various researchers suggested that trainings should be personalized by tailoring the intervention to the individuals' rehabilitation needs and performance levels, thereby improving motivation and adherence [15,16,19]. All 3 cases presented above likely showed positive attitudes toward gamification and used gamification strategies, such as goal setting, reinforcement, and the capacity to overcome challenges, that have been scientifically proven to promote health behavior change and thereby influence health outcomes [20]. In addition, all 3 cases showed aspects of personalization: they chose their own way of training and made personal adjustments in gameplay or goals within their training.

Finally, all patients showed excellent adherence to the training for prolonged periods of time (several years). They were intrinsically motivated to continue, possibly because they felt that the therapy had a positive effect on their functional performance. An extrinsically motivated person requires an external reward to engage in a particular behavior, whereas intrinsic motivation arises from intrinsically rewarding factors. People may follow a training because it makes them feel better (intrinsic motivation) and feeling better may then have external benefits (extrinsic motivation) [21]. Ultimately, motivated people tend to exercise a behavior that is particularly rewarding to them, which may explain why these 3 patients continued to use their self-invented training for many years. However, Case 1 was treated with dopamine agonists, which could have resulted in increased addictive behavior in PD and thus in more adherence to the training. Nevertheless, motivation is an important influencer of adherence and it should be an important part of future interventions in this area.

Comparison With Prior Work

All 3 patients found their own way to train their cognition, but the majority of PD patients are not likely to be able to create such self-invented trainings. However, in some patients, there seems to be a need for a structured way of training cognitive functions. Various traditional cognitive trainings have already been investigated in PD, with small-to-moderate symptomatic effects on cognition, mainly on measures of processing speed, working memory, and executive functions [5,22]. These previous studies had short follow-up periods of maximally 3 months. It would be interesting to see whether these symptomatic effects also persist in the long term and whether the progression of cognitive decline could potentially be delayed (ie, a neuroprotective or disease-modifying effect). However, none of the previous studies investigated the long-term effects on cognition in PD. To date, there is no evidence whether gamified cognitive training can suppress (let alone delay the progression of) cognitive impairment in PD. Many of the investigated cognitive trainings in PD are lacking rewarding gamification stimulants that could stimulate adherence and eventually improve health outcomes even more. In addition, many cognitive training studies had methodological challenges, such as the lack of solid sample sizes based on reliable power calculations. Importantly, showing that gamified cognitive training has disease-modifying effects that extend beyond mere symptomatic effects is very difficult and calls for specific study designs to separate temporary symptomatic improvement from a more sustained protective effect on actual progression [23].

Some efforts have been made to create gamified cognitive assessments, which may add benefits over traditional assessments in terms of reducing stress related to the formal assessment situation. These gamified assessments are usually relatively simple puzzles with, for example, added sound effects to appear as a game. More importantly, they validate well against traditional cognitive assessments [13]. Gamified cognitive assessments can additionally be used to evaluate the performance and adjust the game's difficulty level accordingly [8]. To our knowledge, no fully gamified cognitive assessments have been investigated in PD to date.

Theoretical Bases

Some theoretical bases have been proposed which promote health behavior when used in gamified treatments [24]. According to the self-determination theory, for example, it is assumed that everyone is driven by autonomy, competence, and relatedness [25]. Within games, autonomy can be implemented via features such as choice and structured reward systems, competence can be implemented via personalized challenges and feedback, and relatedness can be implemented via social elements [24]. For gamified treatments in PD patients, the complexity of the apathy-reward-motivation system must also be recognized [26]. Although the exact relationship is not yet clear, apathy is thought to result from dopaminergic depletion in the ventral striatum, substantia nigra, and ventral tegmental area [26]. Indeed, PD patients have a decreased reward sensitivity in an off-dopaminergic medication state [27]. Personalized trainings, with more rewarding elements and interventions that are specifically tailored to their cognitive abilities, will likely improve the self-efficacy of patients. Patients then feel more in control over the events or behaviors with regard to the training, thereby increasing motivation and enhancing resilience to failure [28]. To increase treatment adherence, a potentially ideal cognitive intervention should contain a mix of training elements targeting various cognitive domains but also contain gamified elements. In addition, it is suggested that a personalized challenge level may result in more engagement in the game [29]. Within PD, some computerized cognitive trainings have been investigated, such as RehaCom (computer-assisted cognitive rehabilitation) [30], SmartBrain (28 computerized cognitive exercises) [31], NEUROvitalis (computerized exercises training attention, memory, and executive functions) [32], and InSight (5 exercises training information processing speed) [33], but none of these trainings incorporated gamification or personalization. In other populations, positive effects have been found with health games. For example, the NeuroRacer [34], a game-like training that aims to reduce susceptibility to cognitive interference and adapts the difficulty level to the player's performance levels (personalization), showed positive effects on attention, impulsivity, and multitasking in elderly subjects. Recently, positive results were published for the Project: Evo health game that targets cognitive conditions in children with attention deficit hyperactivity disorder (ADHD) [35]. Although Project: Evo is actually a therapy targeting specific neural circuitries involved in attentional control, the intervention feels like a videogame when it is being performed. The researchers found improvements in working memory and attention, but the treatment was also an attractive way to address ADHD, which is promising when it comes to achieving sustained treatment efficacy over time.

Recommendations for Future Gamified Interventions

In Table 1, we briefly summarize considerations considering the design and evaluation of future gamified cognitive trainings. This table is based on recommendations from the literature on both game development and evaluation guidelines [36].

Table 1. Considerations for developing future gamified cognitive trainings.

Area and consideration[a]	Type
Gameplay	
Adopt levels of increasing complexity (with achievable goals)	Gameplay
Introduce cognitively demanding aspects slowly	Gameplay
Clear user-interface design (large fonts, bright colors)	User-interface
Include a dynamic difficulty adaptation mechanism (interactive)	Personalization
Personalize training content to individual needs in real-time	Personalization
Add social elements (eg, play with grandchildren)	Social functions
Add competitive elements (against oneself, computer, or others)	Social functions
Choose actions that are familiar to patients (daily activities)	Gameplay
Think about fun factors (appealing story, graphics, and sounds)	Gameplay
Set long-term goals to help sustain long-term engagement	Engagement
Provide in-game variance (keep game engaging for longer periods)	Engagement
Reinforce positive performance with visual/audio feedback (reward)	Feedback
Avoid negative feedback	Feedback
Be hesitant with negative progress reports (self-monitoring)	Feedback
Development	
Integrate validated theories (eg, self-determination, motivation)	Design
Use recent serious game development guidelines [36]	Design
Participate with Parkinson disease patients and professionals in design/evaluation	Design
Optionally add other neuroplasticity stimulants (eg, exercise)	Design
(Re)evaluate the game with an evaluation protocol [36]	Evaluation
Procedural	
Provide crystal-clear and guided instructions	Instructions
Guide the patient through the first level(s)	Instructions
Set clear goals (distinguish game targets vs training targets)	Instructions
Adopt cross-platform availability and plug-and-play technology	Availability
Optionally add group-based, therapist-guided booster sessions	Efficacy
Methodological	
Clearly describe the training to aid in replication (publication)	Epidemiology
Compare standardized versus personalized training	Epidemiology
Have a solid sample size	Epidemiology
Report standard measures of disease severity (Hoehn & Yahr Scale, Unified Parkinson's Disease Rating Scale Part III)	Epidemiology
Report standard measures of medication status (Levodopa equivalent daily dosage)	Epidemiology
Report standard measures of cognitive status (Montreal Cognitive Assessment, Mini Mental State Exam)	Epidemiology
Report objective and subjective measures of safety	Epidemiology
Report measures of feasibility and adherence	Epidemiology

[a]Noncomprehensive considerations for gamified cognitive training design (in the field of Parkinson disease); not presented in order of priority and obtained from the wider literature [7,13,15,16,19,20,30,36-39].

Conclusions

Taken together, the 3 patients presented here as well as the recruitment results from a gamified and personalized cognitive training trial [8] may justify the development of more structured ways of training cognitive functions in PD, while incorporating elements to increase adherence such as personalization and gamification. Positive results have already been found with gamified trainings in other populations, and the cases described here suggest that PD is also an attractive area to develop and test gamified cognitive trainings. Our 3 patients also demonstrate enormous creativity and laudable resilience despite having PD. However, the majority of PD patients are not likely to be able to create such self-invented trainings. Researchers, health professionals, patients, and the industry should therefore collaborate to develop motivating and targeted cognitive trainings for persons with PD, for which our considerations offered here can be used. The first steps in this direction have already been taken, and several trials are now ongoing [8,18,40,41].

Conflicts of Interest

None declared.

Multimedia Appendix 1

Short clip of Case 1 training in the racing simulator game.

[MP4 File (MP4 Video), 30MB - games_v7i2e12130_app1.mp4]

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Abbreviations

ADHD: attention deficit hyperactivity disorder
PD: Parkinson disease

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Toronto, ON, M5A 3Y5
Phone: (+1) 416-583-2040
Email: support@jmir.org