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Original Paper

Virtual Reality App for Treating Eating Behavior in Eating Disorders: Development and Usability Study

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Abstract

Background: Anorexia nervosa is one of the more severe eating disorders, which is characterized by reduced food intake, leading to emaciation and psychological maladjustment. Treatment outcomes are often discouraging, with most interventions displaying a recovery rate below 50%, a dropout rate from 20% to 50%, and a high risk of relapse. Patients with anorexia nervosa often display anxiety and aversive behaviors toward food. Virtual reality has been successful in treating vertigo, anxiety disorder, and posttraumatic stress syndrome, and could potentially be used as an aid in treating eating disorders.

Objective: The aim of this study was to evaluate the feasibility and usability of an immersive virtual reality technology administered through an app for use by patients with eating disorders.

Methods: Twenty-six participants, including 19 eating disorder clinic personnel and 5 information technology personnel, were recruited through emails and personal invitations. Participants handled virtual food and utensils on an app using immersive virtual reality technology comprising a headset and two hand controllers. In the app, the participants learned about the available actions through a tutorial and they were introduced to a food challenge. The challenge consisted of a meal type (meatballs, potatoes, sauce, and lingonberries) that is typically difficult for patients with anorexia nervosa to eat in real life. Participants were instructed, via visual feedback from the app, to eat at a healthy rate, which is also a challenge for patients. Participants rated the feasibility and usability of the app by responding to the mHealth Evidence Reporting and Assessment checklist, the 10-item System Usability Scale, and the 20-point heuristic evaluation questionnaire. A cognitive walkthrough was performed using video recordings of participant interactions in the virtual environment.

Results: The mean age of participants was 37.9 (SD 9.7) years. Half of the participants had previous experience with virtual reality. Answers to the mHealth Evidence Reporting and Assessment checklist suggested that implementation of the app would face minor infrastructural, technological, interoperability, financial, and adoption problems. There was some disagreement on intervention delivery, specifically regarding frequency of use; however, most of the participants agreed that the app should be used at least once per week. The app received a mean score of 73.4 (range 55-90), earning an overall “good” rating. The mean score of single items of the heuristic evaluation questionnaire was 3.6 out of 5. The lowest score (2.6) was given to the “accuracy” item. During the cognitive walkthrough, 32% of the participants displayed difficulty in understanding what to do at the initial selection screen. However, after passing the selection screen, all participants understood how to progress through the tasks.
**Conclusions:** Participants found the app to be usable and eating disorder personnel were positive regarding its fit with current treatment methods. Along with the food item challenges in the current app, participants considered that the app requires improvement to offer environmental and social (eg, crowded room vs eating alone) challenges.

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**KEYWORDS**
feeding and eating disorders; anorexia nervosa; bulimia nervosa; binge eating disorder; immersive virtual reality; eating disorders; virtual reality

**Introduction**

Anorexia nervosa is an eating disorder characterized by restriction of energy intake, leading to a significantly low body weight, intense fear of gaining weight, disturbed body perception, and lack of insight into the seriousness of the disorder [1]. At least 90% of individuals with anorexia nervosa are women, with 40% of the identified patients ranging between 15 and 19 years of age [2,3]. According to the Diagnostic and Statistical Manual of Mental Disorders IV, the lifetime prevalence of anorexia nervosa varies from 0.3% to 1.0%, and the mean crude mortality rate is 5% per decade [4,5], varying from 0% to 15.6% [6,7]. Anorexia nervosa is associated with physical problems such as anemia, reduced brain volume, infertility, altered hormonal balance, loss of muscle mass, and osteoporosis. However, most of these physical and mental problems normalize with weight regain [8].

Long-term outcomes in anorexia nervosa treatments are often discouraging. A 2002 review concluded that only 46.9% of anorexia nervosa patients reached full recovery, 33.5% improved, and the disorder became chronic in 20.8% of cases [9]. In 2020, similar outcomes were found in anorexia nervosa patients receiving treatments consisting of eating disorder–focused structured individual therapies [10]. In addition, studies frequently report poor long-term treatment outcomes with high relapse rates [11], dropout rates ranging from 20.2% to 49.6% [12], and a propensity for the anorexia nervosa disorder to transition into other eating disorders [13].

Better treatment outcomes could be achieved when one part of the treatment consists of normalizing eating behavior through eat training [14]. Treatment based on this method typically begins after establishing a baseline eating behavior for each patient by having them eat food on a medical device (Mandometer) that records the cumulative food intake (in grams). In this treatment, patients eat their meals on the Mandometer following a reference curve for food intake over time that is displayed on their own smartphone. The food intake quantity is initially based on the baseline measure but is updated depending on the rate of recovery of the patient [15]. Another part of eat training consists of reducing food avoidance and apprehension around food, which are the key factors responsible for maintaining the starved state [16]. Virtual reality (VR) technology could offer an alternative approach for handling food and to practice eat training in a treatment setting [17].

VR treatment involves immersing an individual in a computer-generated 3D world that is customized according to treatment needs, where the individual can be safely exposed to stressors. Additional benefits of using VR are that it enables repetition as well as exposure control (internal validity) and has high generalizability to other contexts (external validity). Recently, technological advances have greatly reduced the cost of VR technology, thereby increasing its scalability [18]. To date, intervention studies that employed VR have been successful in treating posttraumatic stress syndrome, anxiety syndrome, and smoking [19,20]. In the eating disorder context, most studies that have employed VR used the technology as an assessment tool for exploring body image perception, and the response of virtual foods and environments [21]. One study demonstrated the ecological validity of the approach, with VR food eliciting similar responses as real food in patients with eating disorders [22]. Most of the eating disorder interventions employing VR have aimed to correct a distorted body image [23]. However, VR exposure therapy has also been reported to reduce the anxiety response to food in patients with bulimia nervosa [24]. VR therapy may also be more acceptable to eating disorder patients than other treatment forms. In a study on phobias, VR exposure was more likely to be selected (76% of participants chose VR) and had lower refusal rates than in vivo exposure (3% vs 27%, respectively) [25]. These findings suggest that exposure therapy via VR has internal, external, and ecological validity in the target group, indicating that it can be effective in treating bulimia nervosa and perhaps also anorexia nervosa, and may be more acceptable for end users (patients with eating disorders) [25].

Evaluation of interventions is common; however, the quality of these studies is often poor, which leads to incorrect implementations and findings that are not reproducible [26]. The first step of establishing digital health interventions is usually to gather the functional requirements for development and testing [27]. The mHealth Evidence Reporting and Assessment (mERA) checklist is a useful method for reporting on digital interventions, which has the benefit of providing recommendations for reporting the feasibility of intervention strategies [27]. Another key factor for the successful adoption of a new technology is usability [28], which was defined as “the extent to which a product can be used to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” [29]. To ensure the acceptance and attitude of patients and clinicians, as well as to enhance well-being, reduce risk of harm, and increase accessibility for patients, health technologies should be appropriately designed to the end users’ needs before they are deployed as health interventions [30,31]. One review suggests using multiple methods in performing usability evaluations [29]. Another study found that the System Usability Scale (SUS) was the most common questionnaire used in such evaluations, and recommended the use of quantitative evaluation methods but concluded that further research is needed.
to identify which methods are best suited for different patient groups [28].

The aim of this study was to investigate the perceived usability of a newly developed VR app that simulates eat training and is intended for use in an eating disorder intervention study. As a first step in this development, usability was evaluated by staff involved in eating disorder treatment.

**Methods**

**Participants**

To be eligible for participation in the study, the individual had to be working in an eating disorder clinic and have daily interactions with eating disorder patients as a clinician or physician (eating disorder personnel) or as part of information technology (IT) service (IT personnel). Individuals were invited to participate in the study through emails and personal invitations. Eating disorder patients were not approached at this stage because of the potential risk that participation would result in poorer treatment outcomes and the assessment that many of the questions related to intervention delivery would be difficult for patients to answer.

**Technology**

The HTC VIVE VR system (HTC) was used as the immersive VR technology in this study, consisting of a headset (connected to a computer) through which the VR environment could be viewed, two hand controllers that enabled interaction with the VR environment, and two base stations that enabled motion tracking. To ensure proper performance, the room size should be at least 1.5x2.0 meters. The computer used a NVIDIA GeForce GTX 1060 graphic card, an Intel Core i5-4590 processor, 8 GB of RAM, and the Windows 7 operating system. The software was developed in the Unity engine and ran on the digital game distribution platform Steam (Valve Corporation), using the SteamVR app.

**Instruments**

Four methods were used for the usability evaluation: the mERA checklist, 10-Item SUS, 20-item heuristic evaluation questionnaire, and a cognitive walkthrough. Rather than being forced to respond to each question, participants could leave questions blank if unable to respond.

The mERA checklist is a 16-item checklist that aims to standardize reporting, and enables quick assessment of eHealth and mobile health apps. Adoption of this checklist is meant to improve transparency [27]. The procedure and app allowed the researchers to objectively evaluate the infrastructure and technological platform, and to make a cost assessment (items 1, 2, and 9). A one-on-one interview was held with each participant regarding the items that could not be objectively evaluated (items 3, 4, 5, 7, 8, 10, 11, and 12). The specific question for each item was whether the participant could foresee any obstacles related to the item (eg, how easy it would be to integrate the app and VR system with already existing health care systems) if the app and VR system were to be used in an identical fashion to how eat training is currently performed in a clinical setting. Questions on interoperability and adaptability were answered by all participants (items 3 and 12), whereas questions on intervention delivery, content testing, accessibility, adoption, scalability, and user feedback were answered only by the eating disorder personnel (items 4, 5, 7, 8, 10, and 11). Since the app was at a formative stage, five questions on the checklist were not applicable (items 6, 13, 14, 15, and 16).

The SUS is a validated tool that is widely used to assess the perceived usability of a system. It consists of 10 statements such as “I found the system unnecessarily complex” and “I felt very confident using the system,” which are answered on a 5-point Likert scale with verbal anchors at the extremes from 0 (“strongly disagree”) to 4 (“strongly agree”). The sum result of the SUS is a score ranging from 0 to 100 [32].

The cognitive walkthrough is a usability evaluation method in which evaluators work through a series of tasks required by the system asking a set of questions from the perspective of the user [33]. The purpose of the cognitive walkthrough is to evaluate the ease of use of an interface design to new or infrequent users. In this study, the following four steps of human-computer interaction were evaluated: (1) goals to be completed in the system, (2) determination of currently available actions, (3) selection of actions to be taken, and (4) performance of the tasks and evaluation of the feedback given by the system. We determined whether a participant managed to perform a step for each task by reviewing video recordings of their interaction with the app (eg, Task 3. Read instructions, grab spoon, pick up meatballs, place meatballs on plate, and move to next task; see Multimedia Appendix 1). Video recordings of actions performed by the user in the app were made using the inherent Steam streaming software. The video recordings were complemented with audio recordings on a smartphone.

The heuristic evaluation is a method for evaluating the usability of computer software, focusing on identifying problems with the user interface. As the name implies, this questionnaire evaluates recognized usability principles (heuristics), constituting one of the more informal methods of human-computer interaction. The heuristic evaluation questionnaire used in this study was based on the Weinschenk and Barker [34] classification, which consist of 20 items, for example “User support: does the application provide additional assistance as needed or requested?” Each item was answered on a 5-point Likert scale with verbal anchors at the extremes from 1 (“strongly disagree”) to 5 (“strongly agree”).

**Procedure**

Each participant attended an information meeting, including a VR tutorial, VR eat training, and a usability evaluation (Figure 1). They were informed of the study and encouraged to ask questions, after which they signed a written consent form if they agreed to participate.

The participants were then taken to the VR lab to familiarize themselves with the VR equipment and environment (Figure 2). The VR lab tutorial started with calibration of the app so that a virtual table and chair were in the same position as a real table and chair in the VR lab. The participant was seated on the real chair in front of the real table and was then fitted with the

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VR equipment. At this point, video and voice recording features were initiated. In the VR environment, the controllers were represented by hands. The tutorial was built in steps, with each step being supported by instructions on what tasks to perform to meet the goal to proceed to the next step, which were displayed on a virtual smart tablet present in the VR environment.

The success of each task was evaluated based on the performance of the participants (Figure 3). In the first step, participants used the controller to interact with the “next” button on the virtual smart tablet. Each subsequent step ended by pressing the “next” button. In the second step, a plate appeared on the table and the participant placed the plate at a specific position on the table. In the third step, a pan of meatballs and a spoon appeared; participants had to then transfer the meatballs from the pan to the plate using the spoon. In the fourth step, a pot of potatoes and a fork appeared; participants had to transfer the potatoes from the pot to the plate using the fork. In the fifth step, a sauce boat filled with gravy appeared; participants had to pour gravy from the sauce boat over the plate. In the sixth step, a bowl of lingonberry jam and a spoon appeared; participants had to transfer the lingonberry jam from the bowl to the plate using the spoon. In the seventh step, a jug of water and a glass appeared; participants had to pour water from the jug into the glass. In the final step of the tutorial, participants interacted freely with the served food, cutting and eating it.

Once familiarized with the app, the participant experienced VR eat training in the same manner as eat training with real food is practiced in the clinic. First, the participant was asked to place a healthy portion of food on the plate. Feedback on how close that portion was to a healthy portion was presented on the computer screen (expressed as percentages). Once the screen showed 100%, the participant started to eat. At this point, the training curve for food intake was displayed on the screen, and as the virtual meal progressed, the virtual food intake also emerged on the screen. Similar to treatment of real eating behavior, the participant tried to eat virtually following the training curve [15]. Once all of the virtual food had been consumed, the duration of the meal, amount of food eaten, and rate of eating were presented on the screen, and the participant was given the option to close the app.

After having experienced both the tutorial and VR eat training session, participants sat down with one researcher to answer the SUS, heuristic evaluation, and mERA checklist questionnaires. Initially, the participants were expected to answer the questions alone. However, it became immediately obvious that some questions required clarification and affirmation by the researcher to confirm proper interpretation. Therefore, a researcher was present in the room when the participant filled in the questionnaires to provide help when needed. After completing the questionnaires, participants received a cinema ticket as a reward and they were thanked for their participation.
**Data Interpretation**

Results are expressed as percentage among responding participants. To provide context for the SUS score, the adjective rating scale proposed by Bangor et al [35] was used, where a score of 39.17 to 52.00 is considered “poor,” 52.01 to 72.74 is considered “OK,” 72.75 to 85.57 is considered “good,” and 85.58 to 100.00 is considered “excellent.”

**Ethical Approval**

All procedures were approved by the Swedish Ethical Review Authority (dnr 2019-04249) and followed the Helsinki Declaration. Each participant attended an information meeting and provided written consent for participation.

**Results**

**Participants**

A total of 24 participants (67% women) were recruited, including 19 eating disorder personnel and 5 IT personnel. Their mean age was 37.9 (SD 9.7) years. Eating disorder personnel had worked at an eating disorder clinic for 4.1 (SD 5.7) years. Twelve of the 24 participants (50%) had previously experienced VR, including 42% (8/19) of the clinicians and 80% (4/5) of the IT participants.

IT personnel were only able to answer 20% of the mERA questions intended for them, and these responses were therefore excluded from the analysis of mERA results. The reason given by IT personnel for not being able to answer the questions was that they are not directly involved in the clinical treatment aspects. Eating disorder personnel were able to answer 80% of the mERA questions intended for them and these responses were therefore included in the mERA questionnaire analysis.

**mERA Checklist**

**Item 1: Infrastructure**

In Swedish urban environments, the availability of power supplies and network connections is adequate to support the app; however, it is uncertain whether the infrastructure in rural environments would be sufficient. The size of the room required for the equipment makes it possible to implement in any facility. However, when the space is smaller than 1.5×2.0 meters, there is a risk of signals from the controller and headset not being transferred to the base stations, causing the app to pause.

**Item 2: Technology Platform**

The app performed well on a computer with low hardware specifications (see the Technology subsection of the Methods), but hardware requirements may be higher if other apps are expected to run simultaneously.

**Item 3: Interoperability**

All of the responding eating disorder personnel (100%, 10/10) thought that it would be easy to integrate the app with the clinic’s medical record system, but would be more difficult to integrate with the national care information system. The main
problem mentioned in relation to the national system is that visual presentations are difficult to implement, but simplified presentation of data would be possible.

**Item 4: Intervention Delivery**

All participants thought that during periods of app use, the frequency should be at least once a week. Participants thought that the current app should be used during treatment, with a higher frequency at the start of treatment. They considered that the addition of difficult environmental and social situations (challenges) would make it usable at a similar frequency throughout treatment.

**Item 5: Content Testing**

All eating disorder personnel thought that the app should complement real eat training using VR to expose patients to food, environment, and social challenges. The addition of challenges would require alterations to the app.

**Item 7: User Feedback**

All responding eating disorder personnel were pleased with the state of the app (100%, 14/14) and thought that future interventions would be easy due to the similarities of the app with current clinical treatment protocols.

**Item 8: Access of Individual Participants**

Nine out of 19 (47%) eating disorder personnel thought that the app was usable for the treatment of all eating disorders; the remainder were unsure but stated no specific barriers to use. Other potential barriers identified were age, culture (availability of only one meal), language (only an English version is currently available), and epilepsy. Overall, 16% (3/19) of the eating disorder personnel expressed a concern that the patients may replace real meals with virtual meals, thereby complicating treatment.

**Item 9: Cost Assessment**

The currently used setup (computer and VR set) costs approximately US $1600, which is affordable for both research and clinical purposes. Based on an intervention protocol of 1 hour per week for each patient, a clinic should be able to run an intervention using two VR devices, which would cost approximately US $3200. There is also the added cost of renting space and a part time clinician.

**Item 10: Adoption Inputs**

Eating disorder personnel thought that the app should be introduced early in treatment and be described as an aid to patients, similar to the medical device (Mandometer) currently used by the clinic, which measures food weight and provides feedback on eating behavior.

**Item 11: Limitations for Delivery at Scale**

Regarding limitations at scale, 32% (6/19) of the participants thought that providing technical support for installing, updating, and using the system could cause problems. Moreover, 21% (4/19) of the participants thought that implementation for clinics using other treatment forms could be problematic. Few mentioned costs (11%, 2/19) and time requirements (5%, 1/19) as potential problems for scaling up.

**Item 12: Contextual Adaptation**

Eating disorder personnel agreed that the most important aspect of the app should be eat training and exposure to food, but commented that including aspects of the environment (eg, school dining hall and birthday party) and social challenges (eg, eating with other people, eating when people are talking) could further improve the app. Other suggestions included reducing anxiety by providing relaxing environments. There was also a suggestion to add a reward system, where patients could score points if they managed to succeed in various challenges.

**SUS Questionnaire**

The SUS scores were similar between clinicians and IT participants, with a mean score of 73.4 (SD 9.2) and 73.5 (SD 11.3), respectively (for a total mean score of 73.4, range 55-90), earning an overall “good” rating. Although the sample sizes did not allow for a statistical comparison, the largest discrepancy between single items was found for the question “I think that I would need assistance to be able to use this system,” for which clinicians were less confident that patients would be able to use the app without support (1.3, mean difference −0.9). The highest score was given to the item “I would imagine that most people would learn to use this system very quickly,” with a mean score of 3.5 (maximum score 4).

**Heuristic Evaluation**

The mean score of single items of the heuristic evaluation questionnaire was 3.6 out of 5, and was very similar between eating disorder and IT personnel (3.6 and 3.7, respectively). Mean values of specific items ranged from 2.6 to 4.4. Both eating disorder and IT personnel provided low scores on “accuracy,” with a mean score of 2.6 (SD 1.1). Eating disorder personnel also provided a low score on “user support”, with a mean of 2.9 (SD 1.3), whereas the IT personnel provided low scores on “flexibility,” with a mean of 2.0 (SD 0.7).

**Cognitive Walkthrough**

The only task in which participants faced problems in understanding the goals to be completed in the app was at the initial selection screen (step 1), where 29% (7/24) of the participants needed instructions on how to select between the tutorial and eat training part of the app. All participants were able to determine the available actions (step 2) and select which actions to take (step 3). All participants required further instructions at least once when trying to perform the tasks (step 4). Based on the instructions required for the participant to complete the task, six problems were identified: (1) handling utensils that used “magnetic” properties (ie, where the food latched onto the utensil based on proximity) rather than gravity to interact with food (serving potatoes and lingonberries) was the most challenging issue; (2) the utensils had specific attributes tied to them (ie, the fork was used for picking up food and the knife was used for cutting), which created problems for participants who tried to pick things up with their hands in some cases (controllers not holding utensils) or used both utensils for picking up food; (3) it was not possible to divide the meatballs and the potatoes more than twice, which confused some participants; (4) only one food item (eg, potatoes or meatballs) could be placed on the fork at a time, and most participants tried
to put both on the fork together initially; (5) when drinking, there was a risk of hitting the VR headset with the controller because the water glass was held closer to the controller compared with the fork holding food; and (6) when the VR environment (SteamVR) was improperly calibrated, it became difficult to interact with the items.

**Discussion**

Using the app tested in this study in a clinical setting would likely only face minor infrastructural, technological, interoperability, financial, or adoption problems. Eating disorder personnel seemed to be positive at the prospect of using the app in the clinic. However, there was some disagreement on the protocol of intervention delivery. SUS scores suggested that the system is passable with room for improvement. The heuristics of the user interface was acceptable, identifying user support, accuracy, and flexibility as potential weaknesses. Video and audio recordings of users’ interaction with the app suggest that users knew the goal of each step of the app and understood when they had successfully completed each step. A suggestion for improvement of the app was to add environmental and social stressors, and to use them in a similar manner as the food stressors in the current app.

Despite its early stage of development, compared with other systems, the app performed above average on the SUS [35]. These findings are in line with answers on the mERA checklist, heuristic evaluation, and observations from the cognitive walkthrough. The results also indicate a willingness by clinicians to use the app in treatment, which is important to ensure proper intervention fidelity [36]. Regarding the heuristic evaluation, the lowest scores were given to “accuracy,” “flexibility,” and “user support.” The low “accuracy” scores seem to have stemmed from difficulty in using the fork. This may have been caused by different types of cutlery having different functions associated with them. In practice, this meant that interactions with the fork worked on proximity, similar to a magnet, whereas interaction with the spoon was based on the regular gravitation properties of objects. Both methods of interaction are often used in VR apps, but mixing the two likely resulted in reduced accuracy. The low flexibility score indicates a need for user customization. The next version of the app should therefore include visual and audio information in both Swedish and English, as well as a more varied selection of cutlery (e.g., spoon and fork) and dishes. The low score on user support suggests the requirement of technical support during the intervention. One problem addressed by eating disorder personnel is that there does not seem to be a safe way for individuals with photosensitive epilepsy to use VR equipment. However, this group only accounts for approximately 10% of epilepsy cases in the age range of 7-19 years [37]. Another worry of eating disorder personnel was that patients would replace real meals with virtual meals. Addressing this concern is beyond the scope of this study but should be considered when conducting VR interventions for eating disorder patients.

Responses to the mERA checklist suggested that infrastructural requirements were low using the current VR technology (HTC VIVE). However, some clinics could face issues, especially if rooms serve multiple purposes, which would require the system to be mobile. One solution would be to use more mobile alternatives such as Oculus Quest, which do not require base stations or a computer connection. The low hardware requirements also suggest that most clinics should be able to use the app with their current computers. Even if new computers are purchased for the intervention, the estimated cost of a VR study using current VR technology is low. Given the similarity of the data provided by the app to data already handled by the medical records system of the intended clinics, only minor modifications are required to incorporate the app in treatment. The reason that IT personnel rated the requirement for assistance lower than the eating disorder personnel may be because they were more likely to have used VR before. In the intended intervention, assistance requirements will not be a problem since patients will be assisted by eating disorder personnel. However, if future interventions intend for the app to be used unassisted or outside of the clinic, additional assistance provided by the app is likely required. Despite the concerns that users may need assistance when using the app, the highest usability score was given to the ease of learning how to use the system.

According to participant feedback, the app should be introduced at the beginning of treatment (intervention) and be used in parallel with real-life eat training. The app should be used throughout the treatment course, with a focus on food challenges at the beginning, and environment and social challenges introduced at the end. VR sessions should be administered at least once a week, for at least the duration of a single meal (around 12 minutes), but preferably for a few meal scenarios. In addition, each clinic should have one person on call for technical support when the VR sessions are performed. The proposed intervention protocol has a slightly lower frequency (once per week vs twice) but a longer duration (3 weeks vs treatment duration) than a study on binge eating performed by one of the more prominent groups focusing on VR-based treatment [38]. However, this protocol is similar to the current treatment [15], which eating disorder personnel thought should make implementation easy.

A strength of this study was the high number of eating disorder personnel included, which increases confidence in generalizability of the findings. However, it should be noted that the personnel all had experience in using a similar treatment protocol; thus, clinicians administering other treatment protocols may respond differently. A potential weakness was the use of eating disorder personnel rather than patients with eating disorders. However, many of the questions related to intervention delivery at this early stage of development would be difficult for patients to answer. This, along with the worry that patients may be affected negatively by the app, was why we recruited only eating disorder and IT personnel for this study. After ensuring that the VR technology and the app are safe for eating disorder patients to use, more mature versions of the app should be evaluated by the intended user group. Another potential weakness was that the heuristic evaluation was translated from English to Swedish but has not been validated in the translated language. Owing to the early stage of development, most mERA items could not be objectively evaluated, but instead an opinion was sought from participants.
This is not the intended use of the mERA checklist, which could lead to reduced reproducibility.

Future studies should aim to evaluate usability in eating disorder patients, investigate if VR is effective in changing behavior, and implement the app in an intervention. To ensure scalability to other clinics, especially those less experienced with handling electronic devices as a tool to help treat eating disorders, a clear protocol should be established, similar to that currently existing for handling a medical device (Mandometer) in eating disorder clinics [15]. Due to the immature state of VR as a treatment method, more general studies should also be performed to evaluate how various elements such as modes of information transfer (ie, tactile, visual, and auditory) influence usability and compliance. The app was found to be usable and eating disorder personnel were positive regarding its incorporation in treatment. The app would fit well with current treatment, requiring only minor alterations. The overall consensus was that the app should be introduced at the beginning of treatment, be administered in parallel with real-life training, technical support should be available, and initial app use should be restricted to the clinic. Along with the food type dimension, there were requests by eating disorder personnel to allow changes to the environment and social context (eg, crowded room vs eating alone).

Acknowledgments
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Conflicts of Interest
PS and CB own shares in Mandometer AB, the company that financed the development of the VR app. JN was an employee of Mandometer AB. The other authors have no conflicts of interest to declare.

Multimedia Appendix 1
Tasks performed in the app by participants.

References


 Abbreviations

 IT: information technology
 mERA: mHealth Evidence and Reporting Assessment
 SUS: System Usability Scale
 VR: virtual reality

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Design and Evaluation of User-Centered Exergames for Patients With Multiple Sclerosis: Multilevel Usability and Feasibility Studies

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Related Article:
This is a corrected version. See correction statement: https://games.jmir.org/2021/2/e30326/

Abstract

Background: Multiple sclerosis (MS) is a chronic inflammatory disease of the central nervous system. Patients with MS experience a wide range of physical and cognitive dysfunctions that affect their quality of life. A promising training approach that concurrently trains physical and cognitive functions is video game–based physical exercising (ie, exergaming). Previous studies have indicated that exergames have positive effects on balance and cognitive functions in patients with MS. However, there is still a need for specific, user-centered exergames that function as a motivating and effective therapy tool for patients with MS and studies investigating their usability and feasibility.

Objective: The aim of this interdisciplinary research project is to develop usable and feasible user-centered exergames for the pressure-sensitive plate Dividat Senso by incorporating theoretical backgrounds from movement sciences, neuropsychology, and game research as well as participatory design processes.

Methods: Focus groups (patients and therapists) were set up to define the user-centered design process. This was followed by the field testing of newly developed exergame concepts. Two sequential usability and feasibility studies were conducted on patients with MS. The first study included a single exergaming session followed by measurements. Between the first and second studies, prototypes were iterated based on the findings. The second study ran for 4 weeks (1-2 trainings per week), and measurements were taken before and after the intervention. For each study, participants answered the System Usability Scale (SUS; 10 items; 5-point Likert Scale; score range 0-100) and interview questions. In the second study, participants answered game experience–related questionnaires (Flow Short Scale [FSS]: 13 items; 7-point Likert Scale; score range 1-7; Game Flow questionnaire: 17 items; 6-point Likert Scale; score range 1-6). Mixed methods were used to analyze the quantitative and qualitative data.

Results: In the first study (N=16), usability was acceptable, with a median SUS score of 71.3 (IQR 58.8-90.0). In the second study (N=25), the median SUS scores were 89.7 (IQR 78.8-95.0; before) and 82.5 (IQR 77.5-90.0; after), and thus, a significant decrease was observed after training (z=-2.077; P=.04; r=0.42). Moreover, high values were observed for the overall FSS (pre: median 5.9, IQR 4.6-6.4; post: median 5.8, IQR 5.4-6.2) and overall Game Flow Questionnaire (pre: median 5.0, IQR 4.7-5.3; post: median 5.1, IQR 4.9-5.3). A significant decrease was observed in the item perceived importance (FSS: z=-2.118; P=.03;
Conclusions: The project revealed that the newly developed, user-centered exergames were usable and feasible for patients with MS. Furthermore, exergame elements should be considered in the development phase of user-centered exergames (for patients with MS). Future studies are needed to provide indications about the efficacy of user-centered exergames for patients with MS.

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KEYWORDS
multiple sclerosis; exergame; motor; physical; cognition; usability; feasibility

Introduction

Background
Globally, approximately 2.3 million people have multiple sclerosis (MS) [1]. MS is an immune-mediated chronic inflammatory disease in which focal inflammation causes the degradation of myelin in the nerve fibers of the central nervous system (CNS), resulting in a wide range of symptoms and impairments [2-4]. Depending on the affected CNS regions and the degree of severity, patients with MS can have physical disabilities (eg, motor weakness, spasticity, sensory disturbances, ataxia, and visual loss), cognitive dysfunction (eg, information processing, attention, executive functions, and memory), and fatigue [5-7]. Symptoms and disabilities affect quality of life by increasing the risk of falls, mobility restrictions, and social isolation [5,6,8-14]. Moreover, patients with MS are often physically inactive or have a sedentary lifestyle as a consequence of the abovementioned symptoms and disabilities, initiating a vicious circle of deconditioning and worsening of symptoms [15,16]. MS is commonly diagnosed in young adults between 20 and 40 years of age and thus affects the early stages of their working lives [5]. All these factors lead to an increase in social and health care costs [17,18]. Therefore, there is a huge socioeconomic need to stabilize and counteract physical disabilities and cognitive dysfunctions by introducing effective therapies for patients with MS.

In general, physical exercise is a safe method that can yield beneficial effects such as depending on the training content, muscular strength, and aerobic capacity and, consequently, it improves mobility, fatigue, and quality of life in patients with MS [19-21]. A further training method that counteracts the aspect of cognitive decline is computer-based training. Specific computer-based training seems to positively influence different cognitive functions (eg, information processing, executive functions, and memory domains) in patients with MS [22-24]. However, both methods train the physical and cognitive components separately. A concurrent offering of both training components seems to be promising because this would promote the interplay of physical and cognitive functions and thus add everyday life ecological validity to the training approach [25].

An upcoming training method that concurrently combines the training of physical and cognitive functions is exergaming [26], “technology-driven physical activities, such as video game play, that require participants to be physically active or exercise in order to play the game” [27]. Typically, a player physically interacts with a video game represented on the screen via special controller technologies. Controllers track the player’s movements and mediate them into a virtual game scenario that provides audio-visual feedback. In this way, commercially available exergames (eg, Nintendo Wii, Sony Move, or Microsoft Kinect) have successfully turned living rooms into playful training settings for approximately 10 years [28,29]. Apart from the entertainment market, video game–based training and therapy applications have also established themselves in the fitness and rehabilitation industry (eg, game-based, robot-assisted movement therapy [30,31]; virtually augmented climbing [32]; or exergame fitness training [29,33,34]). Besides the various beneficial effects of exergaming [35-37], the physical-cognitive interaction of exergames seems to trigger an alternating brain-body communication. Depending on the video game stimuli and the body-controller interaction, different cognitive and physical functions can be trained, which makes exergames a promising tool in MS therapy.

In recent years, researchers have started to evaluate exergames as a rehabilitation tool for patients with MS. Exergames proved to be an acceptable, feasible, safe, enjoyable, challenging, and self-motivating tool [38-40]. Kramer et al [41] concluded that the integration of exergames seemed to have a positive effect on training adherence and therefore could support the efficacy of long-term rehabilitation. Video game–based exercises, especially Nintendo Wii Fit, seem to improve static and dynamic balance as well as gait performance in patients with MS [41-44]. Intriguingly, these exercises led to improvements in the myelin sheaths of nerves in the brain areas involved in balance and movement [45]. Robinson et al [46] showed that the physical benefits of Nintendo Wii Fit training were comparable with traditional balance training in patients with MS. Furthermore, 2 recent systematic reviews concluded that exergaming enhanced cognitive functioning, in particular decision-making processes (executive functions) and visuospatial perception, in neurological patients who experience stroke, Parkinson disease, MS, or dementia [40,47]. However, many of the results so far stem from commercially available exergame systems (mainly Nintendo Wii and fewer Xbox Kinect and Sony PlayStation) that have not been developed for specific rehabilitation audiences. A review of exergame training in patients with MS suggested the development of exergames that target the training of a clinically identifiable need for this patient group [48]. For example, Nintendo Wii games did not appear to be entirely suitable for rehabilitation in MS because of a lack of flexibility.
and adaptability to the needs of patients with MS, which require special software development [49].

Human-computer interaction research, sports science, and human movement sciences offer numerous guidelines and frameworks aiming for more attractive and effective full-body motion games for different target populations [28,32,50-57]. Accordingly, these games should consider the needs and constraints of the target population [55,58,59]. One of these frameworks is the dual-flow concept that requires individual adaptable training features, thus ensuring that exergames are user-centered [55]. The dual-flow approach implies that exergame-based training provides an individual and optimal level of physical and cognitive challenge for every trainee throughout each training session by adapting the difficulty and complexity of the game to an individual’s current physical, cognitive, and emotional states and needs in real time. Furthermore, the technology-based system of exergames allows the systematic and individual integration of training principles such as intensity, volume, progression, tailoring, and feedback [60-62]. Specific software algorithms continuously analyze and rate performance, thus allowing real-time adaptations. Recent findings of the international game research debate indicate that a player can be optimally motivated and stimulated with an adaptive game mechanic [29,34,55,63-65]. In combination with an audio-visually appealing exergame scenario (visuals, sound, story, etc), players’ motivation can be increased [64]. Having fun while training with interactive games might have a huge impact on engagement and compliance [66]. Thus, a holistic exergame design approach can achieve an attractive and effective training experience by considering the levels of body, controller, and game scenario [33,67].

**Figure 1.** Iterative and research-based development process.

**Objective input**
(Literature)

**Subjective input**
(Patients and therapists)

**Exergame Concepts**

**Movement science**
(Training principles and concepts)

**Game design & research**
(Game concepts, gameplay, and mechanics)

This interdisciplinary research and development project developed new exergame concepts for the game controller Dividat Senso (Dividat; Figure 2). The Dividat Senso is a pressure-sensitive plate that serves as a game-input device. It uses specific lower body movements (eg, footsteps or weight shifts) to control various game scenarios presented on a screen. Several high-resolution sensors in the plate measure the force dynamically through body movements. The Dividat Senso plate further allows the generation of multidimensional sensory

**Objectives**

In summary, there is a huge potential for developing effective and attractive user-centered exergames that combine training principles with elements of game design and focus on disease-specific deficits to increase motivation and performance and thus to ensure the possibility of successful training. The overall aim of the interdisciplinary research and development work presented here is to develop and evaluate user-centered exergames for the game controller Dividat Senso by incorporating a theoretical background from movement sciences, neuropsychology, and game research, as well as participatory design processes with patients with MS and their therapists. This work aims to contribute specifically to the following: (1) research-based, iterative, co-designed user-centered exergames for patients with MS and (2) the usability and feasibility testing of newly developed exergames by field testing and study trials.

**Methods**

**MS Exergame Concept**

**Design Process**

As a first step, the iterative and research-based development process of the exergame concepts considered the knowledge gained from different user perspectives (patients with MS and therapists) and disciplines (human movement science and neuropsychology as well as game design and research) to holistically generate a potentially attractive and effective user-centered exergame training for cognitive-motor therapy in patients with MS (Figure 1). The multilevel design approach covered important aspects of the exergame concept: the hardware (the Dividat Senso plate), training concept (input movements, training principles, and cognitive tasks), and software (virtual game scenario).
stimuli (eg, auditory, visual, and tactile). To support the trainee and for safety reasons, the plate is surrounded by a handrail.

Figure 2. Original setup of the Dividat Senso.

Rethinking the Dividat Senso Plate (Hardware) and Game Designs (Software)

The design process started by analyzing the existing system and determining its technical opportunities, focusing on the Dividat Senso plate and the game collection, as they were not designed with or for the specific requirements of patients with MS. In this context, the project team visited certain therapy settings (rehabilitation center and physiotherapy) with neurologically impaired patients (MS and Parkinson disease) using the existing system in a therapy session. Furthermore, project members tested the plate and existing games themselves.

The most important finding was that patients often showed similar interaction patterns while playing on the Dividat Senso; patients first focused on the screen to receive the visual game stimuli and then tended to look down at the plate to step on the plate area to trigger the respective game input. This process seems to be important for patients with MS, as the motor learning process can be triggered via cognitive and motor information processing and realization [68]. However, the game control did not leave much room for maneuver, required very precise stepping, and did not make use of the whole plate. Such usage might interrupt movement dynamics and game flow [29,34,64,65] and leave certain gameplay options unused. Therefore, the plate layout was reconsidered, aiming for more intuitive, natural, and everyday-like patterns [34,69,70]. The focus was on using the entire pressure-sensitive plate, allowing the player to keep focusing on the game scenario and thus to stay uninterrupted in the game flow (Figure 3).
Moreover, some of the existing games did not necessarily follow a meaningful design [34] in terms of player perspectives [71] and the audio-visual representations of the cognitive stimuli and the respective motor challenges. For example, a virtual skier skies downhill while avoiding crashing into obstacles. The skier is represented on the screen in a third-person perspective with a top-down view and descends from above the screen but is controlled by sideways movements on the Dividat Senso plate where the left hand and right hand are flipped.

**Rethinking the Training Concepts (Cognitive and Motor Tasks)**

On the basis of the above reflections (usage and interaction patterns), the existing training concepts were also reconsidered, focusing on MS-specific motor and cognitive disabilities (eg, balance and coordination) and disease-specific deficits (eg, degeneration of myelin). Overall, the training concepts were developed and integrated by considering the following specific training principles: (1) type and specificity, (2) intensity, (3) progression, (4) variability, and (5) feedback [60-62]. Literature on exergaming in a therapeutic context was also considered [72].

In this process, some motor functions were considered that seem to be beneficial for patients with MS. Patients with MS often experience, to a variable extent, muscle weakness, diminished dexterity, spastic paresis, sensory dysfunction, gait disturbances, and fall risk, as well as fatigue and depression [5,6,73,74]. Therefore, the training concepts aimed to integrate motor control components, focusing on static and dynamic balance and coordination skills. **Figure 4** shows the preexisting and reconsidered input movement. In terms of cognitive stimulation, the training concept aimed to integrate cognitive functions that may be affected in patients with MS, such as information processing, attention, decision making, error correction, executive functions, and memory [7,73-75].
Figure 4. Input movements, including existing patterns (A, B, and C) and rethought patterns (D, E, and F). Input movements are presented as body models and as patterns that are registered by the pressure-sensitive plate.

A further training concept for exergames that must be mentioned is the dual-task approach. Study findings indicate that patients with MS have impaired dual- or multi-task performances that could result from their deficits in divided attention, resource capacity overload, or differential neural activation [76-80]. In this case, exergames allow the concurrent processing and synchronization of cognitive and motor stimuli and therefore seem to support constant body-brain communication. These processes might be advantageous as they are close to day-to-day activities, such as walking in an enriched real-world environment.

Furthermore, the reconsidered training concepts considered both games that endorse motor learning [68] and games that require moderate continuous exercise performance [81] in order to replicate preliminary findings of physical training on myelin sheath regeneration as well as to specifically target important disability-related structural deficits seen in patients with MS.

Figure 5. Three sketches of potential game scenarios. Different gameplay options, game mechanics, and perspectives served as inspiration during focus groups. The Puddle Jump sketch (A), the Gentle Giant sketch (B), and the Owl Flight sketch (C).

On the basis of the results of the focus groups, personas for the 2 target audiences were developed. The primary aim was to provide patients with MS (predominantly adult females of all ages, ranging from high to low fitness) an attractive and effective training. The secondary aim was to provide physiotherapists (who are open to the use of technology in movement therapy) with a flexible supplementary tool to their traditional therapy methods. Among other outcomes, the focus groups revealed that the design should not be restricted to a specific age or gender group nor to a single game style and input movement concept, because the MS disease pattern is very heterogeneous. Therefore, different exergame scenarios were designed, including different game mechanics, narratives, perspectives, and input movements with the Dividat Senso. Each scenario provided slightly different cognitive and motor challenges and aimed at patients with MS aged around 30-85 years who fulfilled

Focus Groups: Cocreating New Exergame Concepts

Following the rethinking process, new exergame scenarios were designed. To ensure that the concepts were user-centered, the target group (patients with MS and their therapists) was involved from the outset. A semistructured interview guideline was developed based on questions about all elements of the exergame environment (eg, body, controller, and virtual game scenarios). The aim of the focus group interviews was to explore the target group’s experiences with exergames and technology in the context of therapy, as well as to define needs, preferences, and expectations for an optimal exergame setup and its integration into an MS therapy setting. The focus group surveys took approximately 90 minutes and were carried out with 4 physiotherapists experienced in MS therapy, 9 patients with MS, and 2 specialists in neuropsychology. In addition to a list of specific questions, participants’ thoughts and specific wishes for the look and feel of future exergames were assessed using 3 different sketches of potential game scenarios (Figure 5).
Field Research: Initial Concept Testing

In total, 6 box prototypes (Figure 6) were modeled using the game engine Unity 3D and showcased at numerous neurorehabilitation trade shows. After visitors of the trade shows, especially therapists and patients, tested the box prototypes, mock-ups of different themes (street, kitchen, alpine, underwater, forest, garden, oriental, and sci-fi) were shown to them. People could rate their favorite game and choose the theme that would suit them best. Out of the 6 box prototypes, the 3 concepts that were most promising and best rated were retained. The survey showed that both patients and therapists of different gender and age groups rated natural, garden-like game settings the highest.

Figure 6. Unity 3D box prototypes. Based on the input from the focus groups, different game scenarios and mechanics were designed. A and D: Two playful, toy-like 2D prototypes allowing the feet to move freely on the Dividat Senso plate to draw and play with a face. E: 2D scenario allowing free steps or weight shifting. B and C: Two 3D images of the Dividat Senso plate acting as a virtual playground, allowing free steps and jumps. F: 3D Racer scenario with a weight shifting input.

Game Concepts: Design, Redesign, and Finalization

Following the preliminary field research, 3 exergame concepts were designed, including different virtual game scenarios and game mechanics, each demanding other input movements on the Dividat Senso plate. The specific descriptions of the video games, visualization of the input movements, and visual progression overview can be found in Table 1, Figure 4, and Figure 7, respectively. In all 3 exergames, the following training principles of motor learning [68] were integrated specifically to train MS-specific disabilities (eg, balance and coordination) and disease-specific deficits (eg, degeneration of myelin): (1) type and specificity (MS-specific motor and cognitive components; see also Rethiking the Training Concepts and Table 1); (2) intensity and progression (level adjustment and in-exergame adaptation [movement speed avatar, Ladybug] allowing for moderate continuous exercise experiences) [81]; (3) variability (3 exergames to capture different training foci; Table 1); and (4) feedback (scoring and sound effects).
Table 1. Game concepts for the game controller Dividat Senso.

<table>
<thead>
<tr>
<th>Exergames</th>
<th>Ladybug</th>
<th>Scooper</th>
<th>Cloudy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Navigation of a ladybug to collect randomly allocated flowers and avoid collisions with obstacles</td>
<td>Harvesting garden vegetables</td>
<td>Setting the position of the sun (Study 1) or a rain cloud (Study 2) to grow flowers</td>
</tr>
<tr>
<td>Motor components</td>
<td>Static balance and coordination</td>
<td>Dynamic balance, coordination, accuracy, and strength</td>
<td>Static balance, coordination, accuracy, and strength</td>
</tr>
<tr>
<td>Cognitive components</td>
<td>Information processing, anticipation, selective attention, and visual-spatial orientation</td>
<td>Information processing, planning, selective attention, and visual-spatial orientation</td>
<td>Information processing and selective attention</td>
</tr>
<tr>
<td>Motor-level settings (Study 2)</td>
<td>Level 1: Side stepping, tapping or weight shifting&lt;br&gt;Level 2: Side stepping, tapping or weight shifting and stepping to the front to avoid obstacles (stones)&lt;br&gt;Level 3: Side stepping, tapping or weight shifting and stepping to the front to avoid obstacles (caterpillars)</td>
<td>Level 1: Walking and standing on objects for collection&lt;br&gt;Level 2: Walking and squatting on objects for collection&lt;br&gt;Level 3: Walking and jumping on objects for collection</td>
<td>Level 1: Side stepping or tapping&lt;br&gt;Level 2: Side stepping or tapping and squatting to make the cloud rain&lt;br&gt;Level 3: Side stepping or tapping and jumping to make the cloud rain</td>
</tr>
<tr>
<td>Cognitive-level settings (Study 2)</td>
<td>Level 1: Pick all flowers&lt;br&gt;Level 2: Pick bonus flower (2 colors)&lt;br&gt;Level 3: Pick bonus flower (3 colors)</td>
<td>Level 1: Pick all vegetables&lt;br&gt;Level 2: Pick bonus vegetables (2 colors)&lt;br&gt;Level 3: Pick bonus vegetables (3 colors)</td>
<td>Level 1: Water all flowers&lt;br&gt;Level 2: Water bonus flower (2 colors)&lt;br&gt;Level 3: Water bonus flower (3 colors)</td>
</tr>
</tbody>
</table>

Figure 7. Study setup and in-game screenshots of the tutorial and game tested in the first study (A, B, and C) and in the second study (D, E, and F).

Study Design

Two usability studies were conducted to evaluate the usability and feasibility of the newly developed user-centered exergames in patients with MS. From January to February 2019, the measurements for the first study were taken, and from April to May 2019, the training sessions and measurements for the second study were conducted. Figure 8 shows the project process, including the 2 user studies.
In the first study, patients with MS tested each exergame concept (Figure 7) for 5 minutes in a random order. Video recordings and observation protocols for exergame performance and interaction were assessed by trained study investigators at a physiotherapy center (Physiotherapy Langmatten, Binningen, Switzerland). After the exergame sessions, patients rated the System Usability Scale (SUS) and answered predefined interview questions.

In the second study, patients with MS played the redesigned exergame concepts (Figure 7) over a period of 4 weeks. Each patient was trained 1 to 2 times per week at a physiotherapy center (Physiotherapy Langmatten) or at one of the neurorehabilitation centers (ZURZACH Care, Rehaklinik Bad Zurzach, Bad Zurzach, Switzerland, and Reha Rheinfelden, Rheinfelden, Switzerland). In the first training session, the participants tested all 3 exergame concepts at level 1 for motor and cognitive adaptations. In the following sessions, patients could decide which exergames they wanted to play and for how long. This procedure was chosen to obtain an impression of the patient’s preferences. Regarding training progression, levels for motor and cognitive functions were individually adapted from session to session, aiming for moderate training intensities (values between 3 and 4 on the modified Borg scale, which ranges from 1 to 10) over 4 weeks. Furthermore, training time was individually increased from week to week for each patient while ensuring a minimum training time of 20-25 minutes per session. However, as the daily state of patients with MS was unpredictable, the level and training time fluctuated in some cases. In the last training session, each patient replayed each of the exergame concepts by starting from where they had left off at the last training session to familiarize themselves with the concepts before the postmeasurements. Measurements were taken during the first training session and at the last training session. During the exergame performance, video recordings and observation protocols for exergame performance and interaction were assessed. After the exergame performance, patients rated the SUS and answered the Flow Short Scale (FSS), Game Flow questionnaire, and predefined interview questions. The training sessions were supervised by trained researchers and physiotherapists, and the measurements were taken by trained researchers.

The ethics committee of ETH Zurich, Switzerland, approved both study protocols (EK 2018-N-85 and EK 2018-N-124). Before any measurements were taken, all eligible patients provided written informed consent according to the Declaration of Helsinki. Withdrawal for no stated reason was permitted at any time during the study.

**Recruitment and Participants**

In the first study, potential participants were recruited by physiotherapists from a physiotherapy center (Physiotherapy Langmatten). In the second study, participants were recruited by physiotherapists and study investigators from specialized centers for neurological physiotherapy (Physiotherapy Langmatten) and rehabilitation (ZURZACH Care, Rehaklinik Bad Zurzach and Reha Rheinfelden). In both studies, all interested patients were fully informed about the study procedure and the inclusion criteria by physiotherapists and study investigators before screening. Patients who met the initial eligibility criteria and signed the informed consent form participated in a personal interview to screen for mental and physical health. Screened data included demographic data and medical information regarding MS (eg, MS type, leg spasticity, and fatigue). Furthermore, the following 2 questionnaires were assessed to define prevalent MS-related restrictions: the MS Impact Scale [82] and Activities-specific Balance Confidence scale [83].

For the first and second study, the same eligibility criteria were set. Patients fulfilling all the following inclusion criteria were eligible: (1) female or male; (2) aged 25-80 years; (3) clinical diagnosis of MS, including all forms (relapsing or remitting, primary-progredient, secondary-progredient, and progressive-relapsing); (4) stationary and ambulant; (5) able to provide written informed consent and understand instructions; (6) able to stand at least for 10 minutes with the aid of a handrail; and (7) visual acuity including correction sufficient to work on a television screen. Any of the following criteria led to exclusion: (1) conditions that precluded stepping exercise...
(severe spasticity that prevents a person from taking a full step or severe musculoskeletal injury), (2) excessive fatigue that prevented training participation, and (3) exercise intolerance that prevented training participation.

Table 2 illustrates the assessments used for the first and second studies.

<table>
<thead>
<tr>
<th>Category</th>
<th>Explanation</th>
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<tr>
<td><strong>Feasibility</strong></td>
<td></td>
</tr>
</tbody>
</table>
| Training adherence and attrition rate | • Compliance with training sessions  
                                    | • Participants lost at follow-up (dropouts)                                |
| **Usability**                    |                                                                             |
| System Usability Scale           | • Reliable and valid tool providing a global view of subjective usability [84-86]  
                                    | • A score of at least 70 for an “acceptable” solution, below 50 is “unacceptable,” and 50-70 is “marginally acceptable” [86]  
                                    | • 10 items (5-point Likert Scale), score range 0-100                      |
| Flow Short Scale                 | • Used to retrospectively get a typical flow-score for specific kinds of actions or situations [87]  
                                    | • 13 items (7-point Likert Scale), score range 1-7                        |
| Game Flow questionnaire          | • Derived from the Sweetser and Wyeth [53] “Game Flow” model, which determines the key elements of player enjoyment  
                                    | • 17 items (6-point Likert Scale), score range 1-6                        |
|                                  | • 7 main items (items 1-7) building the dimension Game Flow and  
                                    | 10 additional explorative exergame-specific items (items 8-17)          |
| **Feasibility and usability**    |                                                                             |
| Guideline-based interview        | • Qualitative evaluation of the user’s game play experiences  
                                    | • Categories: (1) overall experience, (2) game scenario, (3) Dividat Senso plate (game controller), (4) body and mind, (5) motivation, (6) training, (7) comparison to conventional movement therapy, and (8) others |
| Video recording and monitoring protocol | • Exergame performance  
                                    | • Same categories as for the interview                                   |
| **Training parameters**          |                                                                             |
| Physical and cognitive exertion  | • Modified Borg Scale from 1 to 10 [88]                                    |
| Number of trainings              | • Range from 4 to 8 trainings                                              |
| Training time                    | • How long participants trained per session                                |
| Play preferences                 | • How often each exergame was played                                       |

**Data Analysis**

For quantitative data, statistical analysis was conducted using SPSS (IBM SPSS 26). The level of significance was set at P<.05. The data were compared using the Wilcoxon signed-rank test, as the assumptions for parametric statistics were not met (nonnormally distributed data). The effect size ($r$) was calculated using the following equation [89]:

\[ r = \frac{z}{\sqrt{N}} \]

An effect size of 0.10–0.29 indicates a small effect, an effect size of 0.30–0.49 indicates a medium effect, and $r \geq 0.50$ indicates a large effect [89]. The interviews were assessed by 5 of the authors (1 game researcher and 4 movement scientists) following an iterative thematic coding approach based on qualitative content analysis [90]. For all interviews, the coders individually transcribed and coded the data according to the categories of the interview guidelines. In 2 iterations, the coders discussed the emerging results until an agreement was reached. Finally, two of the authors (1 game researcher and 1 movement scientist) further summarized the findings. A preliminary explorative
analysis was conducted on the observation protocols and videos, but for the purpose of this paper, they were only used to check certain findings from the interview analysis.

**Results**

**Participants**

The participant characteristics are shown in Table 3. At the beginning of the second study, 29 patients with MS were included, while 4 patients with MS dropped out (attrition rate: 4/29, 14%) during the study period. The reasons for dropout were disease-related weakness, physical condition, early clinical release, and scheduling conflicts. In total, participants completed 70 training sessions (mean 4.8 training per participant, SD 1.1) with the exergames. Of the 25 patients with MS, 4 patients with MS missed a training session once and 1 patient with MS missed a training session twice, leading to an attendance rate of 95% (120/126). The reasons for missed training were overload and fatigue after training, illness, absence, date conflict, and holiday. Considering the game preferences in the second study, the participants mostly played Ladybug (1.51 sessions per training), followed by Scooper (1.19 sessions per training), and the least Cloudy (0.91 sessions per training). Overall, no adverse events were recorded in the first and second studies.

**Table 3.** Baseline and training data characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Study 1 (N=16)</th>
<th>Study 2 (N=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender, n (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10 (62)</td>
<td>15 (60)</td>
</tr>
<tr>
<td>Male</td>
<td>6 (38)</td>
<td>10 (40)</td>
</tr>
<tr>
<td>Age (years), mean (SD)</td>
<td>62.1 (13.0)</td>
<td>57.3 (11.2)</td>
</tr>
<tr>
<td><strong>Types of MS</strong>, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>7 (44)</td>
<td>11 (44)</td>
</tr>
<tr>
<td>SP</td>
<td>2 (12)</td>
<td>10 (40)</td>
</tr>
<tr>
<td>PP</td>
<td>7 (44)</td>
<td>3 (12)</td>
</tr>
<tr>
<td>Not applicable</td>
<td>0 (0)</td>
<td>1 (4)</td>
</tr>
<tr>
<td><strong>Therapy stay, n (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambulant</td>
<td>16 (100)</td>
<td>19 (76)</td>
</tr>
<tr>
<td>Stationary</td>
<td>0 (0)</td>
<td>6 (24)</td>
</tr>
<tr>
<td>Diagnosis since (years), mean (SD)</td>
<td>22.73 (13.1)</td>
<td>16.6 (11.7)</td>
</tr>
<tr>
<td>MSIS*, mean (SD)</td>
<td>33.2 (16.7)</td>
<td>34.3 (15.0)</td>
</tr>
<tr>
<td>MSIS physical, mean (SD)</td>
<td>34.2 (20.1)</td>
<td>36.2 (15.5)</td>
</tr>
<tr>
<td>MSIS psychological, mean (SD)</td>
<td>29.7 (23.0)</td>
<td>32.1 (19.2)</td>
</tr>
<tr>
<td>ABC**, mean (SD)</td>
<td>74.7 (11.7)</td>
<td>69.4 (18.2)</td>
</tr>
<tr>
<td>Exergame experience, n (%)</td>
<td>2 (13)</td>
<td>10 (40)</td>
</tr>
<tr>
<td>Number of trainings per participant, mean (SD)</td>
<td>1 (0)</td>
<td>4.8 (1.1)</td>
</tr>
<tr>
<td>Training time per session (min), mean (SD)</td>
<td>15 (0)</td>
<td>19.1 (3.9)</td>
</tr>
<tr>
<td>Borg motor, mean (SD)</td>
<td>3.3 (1.2)</td>
<td>3.8 (1.8)</td>
</tr>
<tr>
<td>Borg cognitive, mean (SD)</td>
<td>4.0 (1.8)</td>
<td>3.5 (1.9)</td>
</tr>
</tbody>
</table>

*MS: multiple sclerosis.
RR: relapsing-remitting.
SP: secondary-progressive.
PP: primary-progressive.
MSIS: multiple sclerosis impact scale.
ABC: Activities-specific Balance Confidence scale.

**Quantitative Data**

In the first study, the median SUS score was 71.3 (IQR 58.8-80.0). The SUS and questionnaire pre-post comparisons of the second study are presented in Table 4.
### Table 4. Questionnaire data (N=25).

<table>
<thead>
<tr>
<th>Questionnaires</th>
<th>Pre, median (IQR)</th>
<th>Post, median (IQR)</th>
<th>z</th>
<th>P value</th>
<th>(r)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Usability Scale</strong></td>
<td>89.7 (78.8-95.0)</td>
<td>82.5 (77.5-90.0)</td>
<td>-2.077</td>
<td>.04</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Flow Short Scale</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluency</td>
<td>5.9 (4.6-6.4)</td>
<td>5.8 (5.4-6.2)</td>
<td>-0.400</td>
<td>.69</td>
<td>0.08</td>
</tr>
<tr>
<td>Absorption</td>
<td>5.7 (4.4-6.6)</td>
<td>5.6 (4.8-6.6)</td>
<td>-0.325</td>
<td>.75</td>
<td>0.07</td>
</tr>
<tr>
<td>Perceived importance</td>
<td>5.8 (5.1-6.5)</td>
<td>6.0 (5.1-6.6)</td>
<td>-0.485</td>
<td>.63</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Game Flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentration</td>
<td>5.0 (5.0-6.0)</td>
<td>6.0 (5.0-6.0)</td>
<td>-0.775</td>
<td>.44</td>
<td>0.16</td>
</tr>
<tr>
<td>Challenge</td>
<td>4.0 (2.5-4.5)</td>
<td>4.0 (3.0-4.8)</td>
<td>-0.210</td>
<td>.83</td>
<td>0.04</td>
</tr>
<tr>
<td>Skills or abilities</td>
<td>5.0 (4.0-5.0)</td>
<td>5.0 (4.0-5.0)</td>
<td>-0.277</td>
<td>.78</td>
<td>0.06</td>
</tr>
<tr>
<td>Control</td>
<td>5.0 (4.5-5.0)</td>
<td>5.0 (4.5-6.0)</td>
<td>-0.732</td>
<td>.46</td>
<td>0.15</td>
</tr>
<tr>
<td>Aim</td>
<td>6.0 (6.0-6.0)</td>
<td>6.0 (6.0-6.0)</td>
<td>-0.816</td>
<td>.41</td>
<td>0.16</td>
</tr>
<tr>
<td>Feedback</td>
<td>6.0 (5.0-6.0)</td>
<td>6.0 (6.0-6.0)</td>
<td>-1.030</td>
<td>.30</td>
<td>0.21</td>
</tr>
<tr>
<td>Immersion</td>
<td>5.0 (5.0-6.0)</td>
<td>5.0 (5.0-6.0)</td>
<td>-0.811</td>
<td>.42</td>
<td>0.16</td>
</tr>
<tr>
<td>Pleasure and liking</td>
<td>6.0 (5.0-6.0)</td>
<td>6.0 (5.0-6.0)</td>
<td>-0.264</td>
<td>.79</td>
<td>0.05</td>
</tr>
<tr>
<td>Dual flow over—challenge</td>
<td>1.0 (1.0-2.5)</td>
<td>1.0 (1.0-2.0)</td>
<td>-0.577</td>
<td>.56</td>
<td>0.12</td>
</tr>
<tr>
<td>Dual flow under—challenge</td>
<td>1.0 (1.0-3.0)</td>
<td>2.0 (1.0-2.8)</td>
<td>-0.418</td>
<td>.68</td>
<td>0.08</td>
</tr>
<tr>
<td>System control</td>
<td>5.0 (4.3-5.0)</td>
<td>5.0 (5.0-6.0)</td>
<td>-1.604</td>
<td>.11</td>
<td>0.32</td>
</tr>
<tr>
<td>Movement</td>
<td>5.0 (5.0-6.0)</td>
<td>5.0 (5.0-6.0)</td>
<td>-0.351</td>
<td>.73</td>
<td>0.07</td>
</tr>
<tr>
<td>Motivation</td>
<td>6.0 (5.0-6.0)</td>
<td>6.0 (5.0-6.0)</td>
<td>-0.816</td>
<td>.41</td>
<td>0.16</td>
</tr>
<tr>
<td>Physical exertion</td>
<td>4.0 (2.0-5.0)</td>
<td>4.0 (2.0-5.0)</td>
<td>-0.158</td>
<td>.88</td>
<td>0.03</td>
</tr>
<tr>
<td>Cognitive exertion</td>
<td>3.0 (2.0-4.5)</td>
<td>3.0 (2.0-4.0)</td>
<td>-0.042</td>
<td>.97</td>
<td>0.01</td>
</tr>
<tr>
<td>Optimal challenge</td>
<td>5.0 (4.0-5.0)</td>
<td>4.0 (4.0-5.0)</td>
<td>-0.842</td>
<td>.40</td>
<td>0.17</td>
</tr>
<tr>
<td>Spatial presence</td>
<td>5.0 (3.5-6.0)</td>
<td>5.0 (4.0-6.0)</td>
<td>-0.361</td>
<td>.72</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\(a^{2}\)Data were analyzed using Wilcoxon signed-rank test.

\(b\)P<.05.

\(c\)The higher the scores, the better the results. This counts for all items that are not specifically marked.

\(d\)The lower the scores, the better the results.

\(e\)The more in the middle field, the better the results.

### Qualitative Data

Findings from the guideline-based interviews of both studies are reported for overall experience (Figure 9), body and mind (Figure 10), games, gameplay experience, and hardware (Figure 11), motivation (Figure 12), and the comparison of exergames with conventional therapy (Figure 13).

In summary, all participants reported an enjoyable, motivating, varied, and fun experience with the exergames, which was a completely new thing for most of them (Figure 9, Figure 11, and 12). They also reported that, in addition to having a lot of fun while being challenged, they felt a clear improvement in the handling (coordination and physical interaction) of the new technology over time (Figures 10 and 11), which made them feel more confident in using it (Figures 9 and 11). On the level of body and mind, participants clearly focused on the virtual gaming world, which distracted them from physical exertion and made it seem very pleasant, albeit challenging, but by no means overstraining (Figure 10). By immersing in the game world, patients were able to forget their everyday worries (often associated with the disease) for the moment (Figure 10). Regarding the potential use of exergames as a therapeutic device, most participants saw the added value of the novel training solution in terms of distraction from everyday life, fun, and the combined body and brain training approach, even though traditional therapy measures were also described very positively and were difficult to compare (Figure 13). A complementary integration of the exergames into therapy could be imagined very well by all patients. Further development of the exergames over the 2 studies was also perceived positively.
Figure 9. Interview data focusing on overall experience. (Some and minority = at least 30% of the participants; many = at least 50% of the participants; most and majority = at least 80% of the participants).

### Table 1

<table>
<thead>
<tr>
<th>1st study</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants were eager and <strong>motivated</strong> to <strong>explore</strong> the exergames.</td>
</tr>
<tr>
<td><strong>Feelings:</strong></td>
</tr>
<tr>
<td>Some participants</td>
</tr>
<tr>
<td>- were surprised by their own performance</td>
</tr>
<tr>
<td>- forgot everything</td>
</tr>
<tr>
<td>- were totally immersed</td>
</tr>
<tr>
<td>- had fun</td>
</tr>
<tr>
<td>Overall, most participants showed interest in participating in the follow-up study, including a training intervention over 4 weeks.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd study before</th>
<th>2nd study after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants commented that the game session was</td>
<td></td>
</tr>
<tr>
<td>- playful</td>
<td></td>
</tr>
<tr>
<td>- interesting</td>
<td></td>
</tr>
<tr>
<td>- fun</td>
<td></td>
</tr>
<tr>
<td>- entertaining</td>
<td></td>
</tr>
<tr>
<td>- not dull</td>
<td></td>
</tr>
<tr>
<td>- physically activating</td>
<td></td>
</tr>
<tr>
<td>- agile</td>
<td></td>
</tr>
<tr>
<td>- challenging</td>
<td></td>
</tr>
<tr>
<td>Participants had <strong>fun</strong>, and most perceived the exergame to be</td>
<td></td>
</tr>
<tr>
<td>- interesting</td>
<td></td>
</tr>
<tr>
<td>- exciting</td>
<td></td>
</tr>
<tr>
<td>- brilliant</td>
<td></td>
</tr>
<tr>
<td>- enjoyable</td>
<td></td>
</tr>
<tr>
<td>- new</td>
<td></td>
</tr>
<tr>
<td>Many participants were glad</td>
<td></td>
</tr>
<tr>
<td>- to have had the <strong>chance to be part</strong> of the study.</td>
<td></td>
</tr>
<tr>
<td>- to contribute to this project.</td>
<td></td>
</tr>
<tr>
<td><strong>Feelings:</strong></td>
<td></td>
</tr>
<tr>
<td>Participants <strong>enjoyed experiencing something new</strong> and had mainly positive feelings. They felt</td>
<td></td>
</tr>
<tr>
<td>- concentrated</td>
<td></td>
</tr>
<tr>
<td>- amused</td>
<td></td>
</tr>
<tr>
<td>- pleased by colors</td>
<td></td>
</tr>
<tr>
<td>- curious</td>
<td></td>
</tr>
<tr>
<td>- full of anticipation</td>
<td></td>
</tr>
<tr>
<td>- comfortable</td>
<td></td>
</tr>
<tr>
<td>- reminded of childhood</td>
<td></td>
</tr>
<tr>
<td>Feelings: Participants’ <strong>feelings throughout the study were very positive</strong>, (in line with pre-interview). Almost all participants</td>
<td></td>
</tr>
<tr>
<td>- enjoyed the games.</td>
<td></td>
</tr>
<tr>
<td>- were transported back to their childhood.</td>
<td></td>
</tr>
<tr>
<td>- felt more and more at ease, the more familiar they became.</td>
<td></td>
</tr>
<tr>
<td>- enjoyed the <strong>deflection from daily-life problems</strong>.</td>
<td></td>
</tr>
</tbody>
</table>

Some participants reported feelings such as **clumsiness and uncertainty** at the beginning. After a short familiarization phase, these feelings turned into **immersion, excitement and ambition** to play and to correctly play the exergame.

**Remembrance:**
- Participants often mentioned **things related to their feelings** during the game sessions.
- Some addressed the **physical activity and agility**.
- Participants often thought of one specific exergame as the **most memorable**.

**Remembrance:**
- Some addressed the **physical–cognitive interaction** performed on the plate.
- Others reported that due to this activity, they could **forget time and daily-life issues**.
- One participant mentioned the **varying response capacity and efficiency** depending on the time of day.

**Changes before/after:**
- Overall, the study did not create noteworthy changes in physical–cognitive conditions because of |
  - short training time |
  - limited number of training sessions |
  |
| Participants commented the most on **mental adjustments**, such as easier handling of the games or higher levels of confidence. |
| One participant experienced a **dramatic physical improvement** and could use new training methods. |
Figure 10. Interview data focusing on body and mind. (Some and minority = at least 30% of the participants; many = at least 50% of the participants; most and majority = at least 80% of the participants).

<table>
<thead>
<tr>
<th>1st study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Perceived physical demand and load:</strong> All participants perceived the exertion as easy to moderate.</td>
</tr>
<tr>
<td><strong>Perceived cognitive demand and load:</strong> Many participants had high concentration levels.</td>
</tr>
<tr>
<td><strong>Focus:</strong> Many participants focused on the game, but were still aware of their own bodies and movements, switching their focus between game and body.</td>
</tr>
<tr>
<td><strong>Steering movements:</strong> Movements felt intuitive but more or less unnatural (eg, due to a participant's impairments).</td>
</tr>
<tr>
<td><strong>Challenge:</strong> Challenge was neither too high nor too low.</td>
</tr>
<tr>
<td><strong>Progression:</strong></td>
</tr>
<tr>
<td>- Difficulty was higher in the beginning.</td>
</tr>
<tr>
<td>- After familiarization, it was easier to play until the game became more complex and faster.</td>
</tr>
<tr>
<td><strong>Multiple sclerosis (MS)-specific limitations:</strong></td>
</tr>
<tr>
<td>- No limitations due to MS were reported.</td>
</tr>
</tbody>
</table>

Some participants cognitively processed what was happening in the game, but could not physically react as fast as required or as intended (eg, to score).  

<table>
<thead>
<tr>
<th>2nd study before</th>
<th>2nd study after</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Perceived physical demand and load:</strong></td>
<td></td>
</tr>
<tr>
<td>- Participants primarily perceived the exertion as challenging.</td>
<td></td>
</tr>
<tr>
<td>- Participants enjoyed controlling the games by body movements.</td>
<td></td>
</tr>
<tr>
<td><strong>Perceived cognitive demand and load:</strong></td>
<td></td>
</tr>
<tr>
<td>- Participants secondarily perceived the cognitive load as challenging.</td>
<td></td>
</tr>
<tr>
<td><strong>Focus:</strong></td>
<td></td>
</tr>
<tr>
<td>- Most participants mainly focused on the game and barely noticed their surroundings.</td>
<td></td>
</tr>
<tr>
<td>- Some participants set their focus differently on the 3 games (depending on their impairments and fitness).</td>
<td></td>
</tr>
<tr>
<td><strong>Steering movements:</strong></td>
<td></td>
</tr>
<tr>
<td>- Movements felt intuitive, comfortable and fairly natural.</td>
<td></td>
</tr>
<tr>
<td><strong>Challenge:</strong></td>
<td></td>
</tr>
<tr>
<td>- Physical aspects seemed to be the main challenge (although physical challenge was not too high). Participants were confronted with handling balance, stability and coordination.</td>
<td></td>
</tr>
<tr>
<td>- Few participants (additionally) mentioned cognitive aspects that challenged them most, such as mental fatigue, concentration on the screen and comprehension of how to play the game.</td>
<td></td>
</tr>
<tr>
<td><strong>Progression:</strong></td>
<td></td>
</tr>
<tr>
<td>- Difficulty was higher in the beginning.</td>
<td></td>
</tr>
<tr>
<td>- After familiarization, it was easier to play.</td>
<td></td>
</tr>
<tr>
<td>- Most participants perceived in-game feedback but not all understood it properly (eg, the meaning of scores).</td>
<td></td>
</tr>
<tr>
<td><strong>Multiple sclerosis (MS)-specific limitations:</strong></td>
<td></td>
</tr>
<tr>
<td>- Others forgot the restrictions caused by their impairment and were surprised how well they performed specific movements during the game session (eg, walking backwards).</td>
<td></td>
</tr>
</tbody>
</table>

| Perceived physical demand and load: |
| - Some participants mentioned a focus on physical aspects (eg, balance and precise performance). |
| **Perceived cognitive demand and load:** |
| - At the end of the study, participants initially set their focus on the mind (eg, they concentrated on the game process). |
| **Focus:** |
| - Most participants mainly focused on the games and barely noticed their surroundings. |
| - Some participants lost their sense of time. |
| **Challenge:** |
| - A third of all participants agreed that it was the combination of physical and cognitive aspects that challenged them the most. |
| **Progression:** |
| - Subjectively perceived improvements were mainly seen in the game “Ladybug” (better motor control, physical precision, improved tactics, and more self-confidence). |
| **Multiple sclerosis (MS)-specific limitations:** |
| - Participants were less concerned and enjoyed a distraction from daily life and impairments. |
Figure 11. Interview data focusing on games, gameplay experience, and hardware. (Some and minority = at least 30% of the participants; many = at least 50% of the participants; most and majority = at least 80% of the participants).

### 1st study

**Favorite game:**
- All 3 game scenarios were considered a favorite by different participants.
- The favorite game was the game participants were the most successful in playing.
- In some cases, they chose the game with which they had the most difficulties that had provided the biggest challenge.

**Gameplay experience:**
- Games were described as comprehensible and generally easy to understand.
- Appearance of the game scenarios was described as enjoyable and appealing.
- Need for instructions and an introductory tutorial was claimed.

**Hardware:**
- Participants mastered the Dividat Senso game control very well.
- They quickly understood how to use the Dividat Senso plate.
- One participant was slightly afraid of falling off the Dividat Senso plate.

### 2nd study before

**Favorite game:**
All 3 game scenarios appealed to the participants.
- The game that was liked the most and was likeliest to be played again was "Ladybug" (great dynamics, rapidity and reaction).
- The second favorite game and second likeliest to be played again was "Scoper" (slowness and comfortable to play).
- The least favorite game was "Cloudy" (meaningfulness, sense of purpose in the game, and easy to play).

**Gameplay experience:**
- Many participants lost their sense of time as they were immersed in the moment.
- If participants experienced time as passing rather slowly or fast, they related it to the newness or their fitness over time.
- Games were described as comprehensible and generally easy to understand.
- In-game instructions were helpful and easy to understand.
- Appearance of the game scenarios was described as appealing (participants liked the colors as well as the clear, bright and delightful pictures).

**Hardware:**
- The comprehension of the game control was evaluated as good – participants generally understood quickly how to handle the in-game navigation.
- The menu navigation was rated controversially (likes and dislikes for the confirmation step to the front plate).
- There was a satisfying sense of the system's sensitivity (participants reported that the system reacted well and immediately).
- Some participants were a bit afraid to step or walk backwards.

### 2nd study after

**Favorite game:**
- The game that was liked the most and was likeliest to be played again was "Ladybug" (dynamics and fast movements).
- The second favorite game and second likeliest to be played again was "Scoper" (movement variations, cognitive challenge and realism of scenario).

**Gameplay experience:**
- Some participants surpassed themselves (e.g., they jumped not knowing they were able to).
- Participants managed and appreciated the game difficulty adjustment.
- Appearance of the game scenarios was described as attractive, lively, colorful and comprehensible.

**Hardware:**
- After the study period, the game control was without exception rated as good and comprehensive.
- Most participants gained more confidence and psychological security with increasing experience.
- The menu navigation was rated controversial (likes and dislikes for the confirmation step to the front plate).
- Participants who required the handrail for more stability generally considered the handrail helpful and appropriate.
**Figure 12.** Interview data focusing on motivation. (Some and minority = at least 30% of the participants; many = at least 50% of the participants; most and majority = at least 80% of the participants).

### 1st study

**Motivation:**
- Most participants were **motivated and had fun playing.**
- Participants could imagine training with the exergames once or twice a week for 10 to 15 minutes.

**Long-term motivation:**
- Majority of the participants wanted **increasing game difficulty** to obtain a constant challenge (eg, complex gameplay, and increased speed and broader game collection.
- Some participants stated that **games would never get boring** because their **daily condition varied (flare-ups)** and the challenge would therefore be maintained.

<table>
<thead>
<tr>
<th>2nd study before</th>
<th>2nd study after</th>
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</thead>
<tbody>
<tr>
<td><strong>Motivation:</strong></td>
<td><strong>Motivation:</strong></td>
</tr>
<tr>
<td>Most participants were <strong>motivated and interested, curious to play</strong> the games and wanted to <strong>perform well.</strong></td>
<td>Participants were driven</td>
</tr>
<tr>
<td><strong>Long-term motivation:</strong></td>
<td><strong>Long-term motivation:</strong></td>
</tr>
<tr>
<td>Participants could imagine the exergames being <strong>motivating and fun to play even after long-term use.</strong></td>
<td>Some participants wanted <strong>new and slightly more challenging</strong> game levels to keep a certain level of challenge over time.</td>
</tr>
<tr>
<td>For some participants, the main motivation was to <strong>get better and increase their physical performance over time.</strong></td>
<td>Only for some participants, collecting points was the motivator (some felt encouraged to break their records, and others did not notice their scores).</td>
</tr>
</tbody>
</table>
Figure 13. Interview data focusing on the comparison of exergames with conventional therapy. (Some and minority = at least 30% of the participants; many = at least 50% of the participants; most and majority = at least 80% of the participants).

### Discussion

#### Overview

This project aimed to contribute specifically to (1) develop research-based, iterative, and co-designed user-centered exergames for patients with MS and (2) determine the usability and feasibility of the newly developed exergames. This was only possible by incorporating the theoretical background from human movement sciences, neuropsychology, and game research, as well as practical skills from game design. Furthermore, this iterative and participatory design process was carried out in close collaboration with patients with MS and their therapists.

In the following sections, the quantitative and qualitative results of the user studies are discussed and set in the context of related work and knowledge in game research and movement science.

<table>
<thead>
<tr>
<th>Exergames:</th>
<th>The exergame sessions were seen as</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fun and challenging.</td>
</tr>
<tr>
<td></td>
<td>an active combination of physical and cognitive challenge.</td>
</tr>
<tr>
<td></td>
<td>a multiple-task training.</td>
</tr>
<tr>
<td></td>
<td>an unconstrained opportunity to move and be active.</td>
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</tbody>
</table>

Compared to medical fitness training, participants felt less physically challenged during the gameplay.

<table>
<thead>
<tr>
<th>Therapy:</th>
<th>Physiotherapy is generally perceived to be less active, beneficial and soothing.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The focus is mainly on physical functions and the aim is to relearn processes and efficiently use the remaining body functions.</td>
</tr>
<tr>
<td></td>
<td>Participants emphasized the cooperation between therapist and patient and the definition of a long-term goal.</td>
</tr>
<tr>
<td></td>
<td>Some mentioned that mistakes and failures in physical progress were better addressed in therapy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exergames:</th>
<th>The exergame sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>were seen as a potential supplementary part of therapy by the majority of participants.</td>
</tr>
<tr>
<td></td>
<td>were a well-received and well-balanced combination of body and brain training.</td>
</tr>
<tr>
<td></td>
<td>distracted from daily problems and concerns.</td>
</tr>
<tr>
<td></td>
<td>were enjoyable.</td>
</tr>
<tr>
<td></td>
<td>caused loss of sense of time as participants were immersed in the moment</td>
</tr>
<tr>
<td></td>
<td>increased self-confidence and physical fitness in daily-life activities.</td>
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</tbody>
</table>

Compared with conventional therapy, the exergames were more fun, entertaining and motivating for movement.

<table>
<thead>
<tr>
<th>Therapy:</th>
<th>After the study period, participants compared the exergame sessions with conventional therapy in a similar way to before the intervention.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participants mentioned that conventional therapy was more individual.</td>
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</tbody>
</table>

Integration of exergames into therapy: Participants would welcome a combination of both training approaches.

1st study

Exergames: For most participants, the exergames were more motivating than the conventional therapy, because they were

- fun to play.
- great brain training.
- a distraction from daily problems and concerns.
- a new training environment.

Therapy: For some participants, conventional therapy and exergames were completely different and hard to compare.

Some participants preferred a combination of both trainings for maximum benefit.

A few participants preferred the conventional therapy because

- they could train more specifically.
- they could feel and know the materials they are training with.
- they liked the interaction with the therapist or animals.

Integration of exergames into therapy: Keep it simple and effortless because patients already have quite a busy daily program or need help to get to therapy or to leave the house.

<table>
<thead>
<tr>
<th>2nd study before</th>
<th>2nd study after</th>
</tr>
</thead>
</table>

Exergames: The exergame sessions were seen as

- fun and challenging.
- an active combination of physical and cognitive challenge.
- a multiple-task training.
- an unconstrained opportunity to move and be active.

Compared with conventional therapy, the exergames were more fun, entertaining and motivating for movement.

Therapy: Physiotherapy is generally perceived to be less active, beneficial and soothing.

The focus is mainly on physical functions and the aim is to relearn processes and efficiently use the remaining body functions.

Participants emphasized the cooperation between therapist and patient and the definition of a long-term goal.

Some mentioned that mistakes and failures in physical progress were better addressed in therapy.
as well as research in the field of MS. Quantitative and qualitative data revealed certain exergame elements that are specific to patients with MS and can become key features for the further development of user-centered exergames for this heterogeneous target group. An outlook on future approaches in user-centered MS-specific exergame development and research will be provided.

**Shift of Focus**

After the second study, patients often reported a *shift in their focus* from the physical to the cognitive level when playing exergames. Some patients even reported a shift of focus from their impairments to their actual skills and abilities, which they found to increase over the period studied. A study in older adults showed that exergame training increased the participants’ confidence and research connected this confidence with increased self-efficacy [91,92]. One participant could even use advanced training methods in his regular therapy at the end of the second study. The exergames allowed the patients a sense of control over their tasks, as described by Sweetser and Wyeth [53]. The more familiar participants became with the exergames and the more they trained their own gameplay strategies and body movements, the more secure, confident, immersed, absorbed, and “in the flow” they became with the exergame. The flow feeling was described not only in the interviews but also in the FSS and Game Flow questionnaire, illustrated by a high rating in several questionnaire items as well as by a significant decrease in the questionnaire item perceived importance. The decreased perceived importance item seems to indicate that the gaming challenge of the exergames was more enjoyable, as patients have attached less importance to the gaming outcomes [93]. This might have been caused by the shift of focus, the increased sense of control, the familiarization process, and higher flow feeling. Furthermore, some patients reported that gaming time distracted them from their daily-life problems and their MS-related impairments. This is in line with the findings of related studies [53,91,94].

**Heterogeneity of Patients With MS**

The heterogeneity of patients with MS, including the individual course of the disease (eg, wide range of symptoms and unpredictable flare-ups), as well as demographic details (eg, wide range of age), was also reflected in the interviews. Patients reported that game content, challenge, and progression should always be adaptable to their individual physical, cognitive, and mental requirements and their daily form [51,72,95]. Therefore, an exergame for patients with MS should allow an individually adaptive training focus, taking into account physical, cognitive, and mental aspects, to correspond with the heterogeneity and fluctuations of the disease pattern. The exergames covered 3 different types of game control and content; each exergame included 3 levels for motor and cognitive functions. Another relevant aspect is security, especially in therapeutic environments [72]. In this project, the patients could use the handrail to support exergame performance due to the insecurity of their physical stability and capacity. This security support was greatly appreciated, as presented in the results of our study. Overall, no adverse events were recorded during the entire duration of the project. The wide age range in patients with MS brings very different previous experiences in using technology [96]. Thus, even for older adult patients without previous technology use, the exergames need to be self-explanatory and easy to use (including help from therapists). In terms of the system’s usability in the heterogeneous study group, the iterative, participative, and interdisciplinary design process of this project was very successful as the SUS increased from study 1 to study 2. In study 2, the SUS dropped from pre- to postmeasurement. The novelty of the exergame might have distracted patients’ focus away from the usability barriers, explaining the high SUS score at the premeasurement. Furthermore, with each additional session, participants had more time to test the system and explore usability barriers. Nevertheless, the SUS in study 2 remained at a level that can be described as a usable exergame system for patients with MS [86,97].

**Training Motivation and Challenges**

Most patients were motivated to train by exergames and enjoyed the requirement of physical activity for playing them. This is in line with a previous study that interviewed patients with MS about Nintendo Wii Fit [39]. However, due to the user-centered development steps and therapy focus, it may be that the training motivation was even higher than in studies that used conventional exergames [48]. One of the main motivational drivers was to improve the player’s body functions, to be immersed in another world, and to be distracted from daily life for the duration of the exergame session [53]. Interestingly, interviews revealed that most patients preferred more challenging games (but still not overchallenging). This was also reflected in the number of sessions in which patients chose to play the most challenging exergames. This challenging situation, in combination with the skill balance of the exergames, may have facilitated the abovementioned flow state during the training sessions [98]. Exergames should provide individually challenging but still feasible gaming experiences to increase training motivation and therefore possible training-related improvements [53]. To maintain their motivation, patients also wished for more challenging and different games or levels over time in future trials.

**Training Intensity and Progress**

An exergame should be able to adapt to the individual patient at a physical and cognitive level to meet the heterogeneous and individual requirements of patients with MS and to allow for an *optimal training zone* [51,95]. For this reason, the design integrated individual levels for physical and cognitive functions into the exergames, allowing for an individually challenging game for patients with MS. To extend the playfulness and effectiveness of the exergames in the future, the assessment of certain motor and cognitive parameters (objective) or rating scales (subjective) could help to define an individual training area [99-102]. The integration of in-exergame, real-time adaptation could help to maintain a predefined optimal training zone in a training session and over a longer period (progression) [51,102,103]. In this project, participants had to rate each training session for physical and cognitive perceived exertion, allowing the training load to be adapted for the upcoming sessions. The results of the perceived exertion ratings showed
that the newly developed exergames allowed for a moderate training load on the cognitive and physical levels in a single training session and over the training period. For aerobic and strength exercises, moderate training is recommended in patients with MS [104]. However, it is possible that high training intensities, such as those used in high-intensity interval training, might be even more beneficial [105]. Nevertheless, a moderate training intensity seems to be an appropriate approach for exergames to trigger possible motor learning processes without negatively influencing movement execution in patients with MS [68,81].

Exergame as an MS Therapy Tool

Interviews showed a strong acceptance of the exergames by patients (even in the first study). The majority would welcome the integration of exergames into their conventional therapy because of their appealing nature and beneficial motor-cognitive training approach [40,106]. The combined training regimen allows for the concurrent processing and synchronization of cognitive and motor stimuli and therefore can trigger brain-body communication. Patients with MS can have impaired dual- or multi-task performance due to possible deficits in divided attention, resource capacity overload, or differential neural activation [76-80]. Furthermore, exergames allow the integration of the patient’s conventional therapy progress in physical and cognitive functions and provide a daily-life environment in terms of the combined cognitive-motor training. However, some patients missed the social component and interaction with the therapists. Therefore, it might be interesting to specifically integrate the therapist(s) into the exergame experience by in-exergame interaction, allowing training adaptation and support. This finding is in line with recent exergame studies in patients with MS and older adults that emphasize the importance of social interaction in exergames to increase motivation [91,103]. Moreover, social interaction is a part of the Game Flow model proposed by Sweetser and Wyeth [53]. Overall, user-centered exergames seem to be a very promising therapy tool for patients with MS, considering the abovementioned aspects of training and design principles.

As a next step, further research and development work will deepen the knowledge of design principles in MS exergames and reveal additional insights. To meet the heterogeneous spectrum of MS and to provide an individually attractive and effective training and therapy tool, the newly developed exergames will be further iterated and extended based on the findings of the usability and feasibility studies. Furthermore, new types of use will be implemented, such as playing a multitask version of the exergames that involve upper-body input movements or sitting in a wheelchair. Moreover, further balancing game mechanics will be implemented, as well as extending the types of input, movement ranges, and tracking zone.

Limitations

There are some limitations that can be reported for this study. In the first study, participants were trained only once with the exergames, whereas they trained multiple times in the second study. Therefore, participants might have had the chance to reflect more on and better familiarize themselves with the games in the second study, while they had only one attempt in the first study. Additionally, their feedback might have been influenced by the novelty effect. Furthermore, study testing was conducted at various clinics and institutions and it did not focus on measures of effectiveness. However, it should be emphasized that these studies should be conducted in the context of developing a complex intervention for health care settings. Within this context, intervention development contains different mandatory steps that should be taken in a sequential order [107]. In that sense, this study reflects a preintervention stage in which important principles and necessary actions for this stage were considered [107]. These findings justify continuing with studies that focus on the outputs and effects in clinical trials [107].

Conclusions

The aim of the presented research and development work was to take the first step in the new field of user-centered exergames for patients with MS, to evaluate the usability and feasibility of the newly developed exergame concepts, to learn from the findings, and to derive design guidelines for future research and development projects in this field.

The quantitative and qualitative results of this project showed that the developed exergames were usable, feasible, well accepted, and enjoyable for patients with MS. Furthermore, the results indicated preliminary positive effects regarding the attractiveness of the newly developed, user-centered exergames. Participants enjoyed the motivating, varied, and fun experience with the exergames, which were both fun and physically as well as cognitively challenging and allowing them to forget their everyday worries (often associated with the disease) for the moment. Moreover, specific exergame elements were identified: control mechanisms through audio-visual design, adaptation of the individual difficulty level, game concept diversity addressing the patients’ heterogeneity, involvement of training principles, and considerations of the interaction of physical and cognitive impairments, especially brain-body communication.

Considering the points of discussion and design guidelines, user-centered exergames can be a promising training approach to improve physical and cognitive functions, especially brain-body communication in patients with MS. Thus, user-centered exergames might have positive effects on quality of life by reducing the risk of falling, mobility restrictions, and social isolation. Furthermore, the strengthening of body functions such as balance, coordination, and cognition seems to be a promising way to break the vicious circle of deconditioning. The evaluation of the effects of a user-centered exergame will show how far a user-centered exergame might complement or even surpass the results of conventional (exergame) approaches in patients with MS.
Acknowledgments

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Authors’ Contributions

AMN and AS conceptualized, designed, and drafted the manuscript. EDB and SF contributed substantially to the conception and design of the manuscript. AMN, AS, SB, SH, and YH created the study design, compiled the training protocols, and selected the assessment methods for the first study. SH conducted the study (supervised by AMN, AS, and RS). For the second study, AMN, AM, AS, BF, SB, and YH created the study design, compiled the training protocols, and selected the assessment methods. AM and BF conducted the study (supervised by AMN, AS, RS, and SF). SB and YH designed the exergame environments for both studies (supported by AMN, RB, and UG). AMN and AS led data analysis and interpretation; EDB and SF contributed to the latter. All authors critically reviewed and approved the final manuscript.

Conflicts of Interest

EDB was a cofounder of Dividat, the spin-off company that developed the exergame plate used in this study, and is associated with the company as an external advisor. No revenue was paid (or promised to be paid) directly to EDB or his institution over the 36 months before the submission of the work.

References


Abbreviations

- **CNS**: central nervous system
- **FSS**: Flow Short Scale
- **MS**: multiple sclerosis
- **SUS**: System Usability Scale
How Gameful Experience Affects Public Knowledge, Attitudes, and Practices Regarding COVID-19 Among the Taiwanese Public: Cross-sectional Study

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Abstract

Background: In 2019, with the COVID-19 pandemic sweeping across the globe, public health systems worldwide faced severe challenges. Amid the pandemic, one simulation game, Plague Inc., has received substantial attention. This game has indirectly drawn greater public attention to public health issues by simulating pathogen transmission and disease symptoms.

Objective: Against this backdrop, this research investigates whether the gameful experience of Plague Inc. has indirectly affected public knowledge, attitudes, and practices (KAP) regarding COVID-19.

Methods: An online survey was conducted through social networking services in Taiwan from May 6-28, 2020.

Results: A total of 486 subjects participated in this study, of which 276 (56.8%) had played Plague Inc. This study had several findings. First, participants who had played Plague Inc. demonstrated higher levels of knowledge ($P=.03$, median 7, IQR 7-8) and attitudes ($P=.007$, median 8, IQR 7-8) than participants who had not played Plague Inc. (knowledge: median 7, IQR 6-8; attitude: median 7, IQR 6-8). Second, there was a significant correlation between creative thinking ($ρ=.127, P=.04$) and dominance ($ρ=.122, P=.04$) in attitude. Finally, there was a significant correlation between creative thinking ($ρ=.126, P<.001$) and dominance ($ρ=.119, P=.049$) in practice.

Conclusions: Serious games highlighting the theme of pathogen transmission may enhance public knowledge and attitudes regarding COVID-19. Furthermore, the creative thinking and dominance involved in gameful experiences may act as critical factors in public attitudes and practices regarding COVID-19. These findings should be further verified through experimental research in the future.

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KEYWORDS

COVID-19; knowledge; attitude; practice; serious game; gameful experience

Introduction

At the end of 2019, an outbreak of pneumonia of unknown cause was detected in Wuhan, China, and it was quickly discovered to be caused by a novel coronavirus, SARS-CoV-2 [1]. On January 21, 2020, Taiwan reported the first confirmed COVID-19 case overseas [2]. As of March 21, 2021, more than 270 million diagnosed cases and 1 million deaths had been reported globally [3]. Although vaccines are considered one of the means of prevention of infectious diseases such as COVID-19, it takes time to verify their safety before they can be brought to market [4].

In the face of the severe threat of COVID-19, implementing controls on health care services and communities has been
deemed an effective strategy [5]. In addition, a general population with higher levels of knowledge regarding pathogens is considered more likely to adopt the correct preventive measures and thereby reduce the prevalence rate of infections [6,7]. Therefore, many governments in the world have proactively provided the latest valid COVID-19 information and guidelines on epidemic prevention to their citizens using mainstream media or social media [8].

Promoting public attention toward health and medical care using game feedback has been proposed, as it helps the public understand possible threats to health and medical challenges when facing a difficult situation related to public health and safety [9]. The Centers for Disease Control and Prevention in the United States and the University of Derby in the United Kingdom have also attempted to impart knowledge about virus transmission and microbiology using educational games [10,11].

Teaching medical knowledge through the form of games has been found to be as effective as traditional text-based teaching methods [12]. In addition to teaching accurate information in a guided and context-based manner, incorporating knowledge pertaining to food and drug safety into video games has been proven to effectively raise the level of relevant knowledge among youngsters [13,14]. Moreover, teaching cardiopulmonary resuscitation through serious games has also been shown to result in a higher retention rate of knowledge and skills [15,16]. Teaching hand hygiene and diarrhea prevention methods through educational games has been confirmed to enhance users’ awareness and practice of public health habits [17,18]. Although serious games have potential for use in medical education and promote proactiveness in learners, it is necessary to strike a balance between instructional theories, educational content, and game interaction to effectively enhance learning performance [19].

**Plague Inc.** is a pathogen simulation game that attracts widespread public attention whenever a pandemic breaks out. This game introduces the public to epidemiology in an unconventional way, allowing users to obtain knowledge of the transmission and characteristics of pathogens through gaming [20]. As a form of new media, **Plague Inc.** employs simple graphics but has diverse charts and functions (Figure 1) [21]. The public may acquire scientific knowledge through intuitive simulation games. In addition, students may also learn about and analyze pathogen transmission and disease symptoms through gameful experiences [22,23].

However, the behaviors that players exhibit while playing games are not just intended for entertainment and recreation. Players’ personality traits are believed to be projected onto their behavior and choices during a game [24,25]. In particular, educational issue–based games not only integrate common gaming elements such as points, badges, and rankings into their design but also offer experiences that enhance extrinsic and intrinsic motivations for players [26-29]. Gamification technology has been found to have a positive effect on health and well-being [30]. Moreover, it has also been deemed to have an important mediating role in health behaviors [31]. Gamification technology has proven to be an effective tool for clinical nursing skill training. However, users’ feelings and attitudes toward the gamification content should be considered [32]. In addition, both gamification technologies and gameful experience can result in psychological or behavioral changes [33].

**Figure 1.** Game guild levels of Plague Inc.

**Objective**

This research aims to investigate and explore the effects of gameful experience of **Plague Inc.** on public knowledge, attitudes, and practices (KAP) regarding COVID-19 through online surveys.

**Methods**

**Study Design**

This research used a cross-sectional study design to explore the impact of Taiwanese gameful experiences on KAP regarding COVID-19.
From May 6-28, 2020, we collected data through an online survey, the link to which was published on social networking services (such as Facebook, PTT Bulletin Board System, internet game forums).

The target population was residents of Taiwan, the population of which was 23,591,920 [34] in April 2020. We used the sample size calculator provided by Rao Soft Inc and selected a 95% confidence level, 5% margin of error, and 23,591,920 population size; the calculated recommended sample size was 385.

This study was conducted in line with the Declaration of Helsinki. All participants were anonymous and provided informed consent. They clearly understood the research content in the online questionnaire [35]. The survey information sheet contained an introduction, background, goals, anonymity statement, and questionnaire descriptions. The average survey completion time was 5 minutes.

**Survey Instrument**

The online survey consisted of four parts: demographics, KAP of COVID-19, game experience of *Plague Inc.*, and a gameful experience scale.

The first part includes demographic variables such as gender, age range, education, living arrangement, and occupation.

The second part pertains to the revised COVID-19 scale. The scale contains 27 questions on the three dimensions of COVID-19—namely, knowledge, attitudes, and practices. Each dimension has 9 questions, with 0 as the lowest score and 9 as the highest. Respondents are required to select “Yes,” “No,” or “Uncertain” for each question. For each correctly answered question, one point is added to the total score of the dimension that contains the question. Moreover, no point was awarded for questions with an incorrect or “Uncertain” answer.

The original scale was used to discuss the KAP regarding Middle East respiratory syndrome coronavirus (MERS-CoV) during the annual Hajj pilgrimage [36], and it was adjusted and translated to Chinese. In addition, five experts in clinical medical treatment and public health were invited to examine the questionnaire content to ensure the questionnaire’s validity. The questionnaire is shown in Table 1.

The third part is about gameful experience of *Plague Inc.*, including “ever played *Plague Inc.*,” “time since last played,” and “total playtime ranges.” In this part, screenshots were used to describe the game’s content (Figure 2).

The fourth part is the gameful experience scale consisting of 27 questions, divided into 6 dimensions: enjoyment, absorption, creative thinking, activation, absence of negative affect, and dominance [37]. The scale is a 5-point Likert scale, with options from 1 (strongly disagree) to 5 (strongly agree).

This scale was also used in nursing-related research and was considered to demonstrate excellent reliability and validity. It can be used to evaluate nursing students’ gaming experiences during training [38]. Three practitioners from the gaming industry were invited to give suggestions on modifying the questionnaire after translation.
Table 1. Questionnaire of knowledge (K), attitudes (A), and practices (P) regarding COVID-19.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Correct response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1. The incubation period of COVID-19 is from 2 to 14 days.</td>
<td>81.3</td>
</tr>
<tr>
<td>K2. Stomach cramps, loss of appetite, nausea, and vomiting are the main symptoms of COVID-19.</td>
<td>38.9</td>
</tr>
<tr>
<td>K3. People with comorbidities are more likely to be infected.</td>
<td>77.0</td>
</tr>
<tr>
<td>K4. COVID-19 spreads through close contact with an infected person, such as caring for and/or living with them.</td>
<td>94.7</td>
</tr>
<tr>
<td>K5. The primary source of COVID-19 is a plant.</td>
<td>89.1</td>
</tr>
<tr>
<td>K6. Antibiotics are the first line of treatment.</td>
<td>52.5</td>
</tr>
<tr>
<td>K7. Vaccinations for COVID-19 are available.</td>
<td>91.4</td>
</tr>
<tr>
<td>K8. COVID-19 can be fatal.</td>
<td>96.9</td>
</tr>
<tr>
<td>K9. Isolation of patients with COVID-19 is essential to ensure effective implementation of infection control measures.</td>
<td>99.0</td>
</tr>
<tr>
<td>A1. Do you agree that there is no risk of contracting COVID-19 when going out and traveling?</td>
<td>83.7</td>
</tr>
<tr>
<td>A2. Do you agree that taking antibiotics can treat COVID-19?</td>
<td>48.8</td>
</tr>
<tr>
<td>A3. Do you agree that pain medication and/or fever medications cannot relieve COVID-19 symptoms?</td>
<td>38.7</td>
</tr>
<tr>
<td>A4. Do you agree that washing your hands with soap and water for at least 30 seconds can prevent disease transmission?</td>
<td>95.7</td>
</tr>
<tr>
<td>A5. Do you agree that avoiding undercooked meat or food prepared under unsanitary conditions can prevent the transmission of disease?</td>
<td>87.4</td>
</tr>
<tr>
<td>A6. Do you agree that avoiding contact with live animals such as bats can prevent the spread of disease?</td>
<td>86.6</td>
</tr>
<tr>
<td>A7. Do you agree that avoiding contact with ill people can prevent the spread of disease?</td>
<td>97.3</td>
</tr>
<tr>
<td>A8. Do you agree that before attending public gatherings or traveling, one must have the necessary information about COVID-19?</td>
<td>95.9</td>
</tr>
<tr>
<td>A9. Do you agree that reporting COVID-19 symptoms to local health authorities is essential to prevent further disease transmission?</td>
<td>98.8</td>
</tr>
<tr>
<td>P1. At a public gathering, did you cover your mouth when sneezing/coughing?</td>
<td>97.3</td>
</tr>
<tr>
<td>P2. At a public gathering, did you wash your hands with soap and water after sneezing/coughing?</td>
<td>59.5</td>
</tr>
<tr>
<td>P3. At a public gathering, did you wash your hands before preparing or eating foods?</td>
<td>80.7</td>
</tr>
<tr>
<td>P4. At a public gathering, did you wash your hands after contact with possibly contaminated surfaces or materials?</td>
<td>85.0</td>
</tr>
<tr>
<td>P5. At a public gathering, did you avoid close contact with people when you were sick?</td>
<td>91.6</td>
</tr>
<tr>
<td>P6. At a public gathering, did you wear a face mask in heavily crowded areas?</td>
<td>96.7</td>
</tr>
<tr>
<td>P7. At a public gathering, did you share cups or eating utensils with other people?</td>
<td>78.8</td>
</tr>
<tr>
<td>P8. Did you consult a health care worker during a public gathering if you had a fever, cough, or difficulty breathing?</td>
<td>92.4</td>
</tr>
<tr>
<td>P9. At a public gathering, did you avoid direct hand contact with your eyes, nose, and mouth?</td>
<td>78.0</td>
</tr>
</tbody>
</table>

https://games.jmir.org/2021/2/e26216
**Game**

Plague Inc. is a strategic simulation game that simulates how various pathogens are spread throughout the world. It was released on the App Store and Google Play in 2012. In 2014, Plague Inc: Evolved was launched on Steam, a platform for PC games.

At the beginning of each game, players can repeatedly spread new pathogens to different countries. Using DNA points in the game, players try to achieve the goal of eliminating all of mankind by employing different modes of transmission, symptoms, and abilities, and influencing the infectivity, severity, and lethality of the viruses.

Players may indirectly control the speed at which infectious pathogens spread by selecting different routes of transmission, as shown in Figure 3. In particular, the game simulates how pathogens spread via airplanes and boats, increasing the number of infected countries and individuals.

Players may change the infectivity and lethality of pathogens by selecting different symptoms, as shown in Figure 4. They may keep the death toll from ascending too rapidly by balancing infectivity and lethality, while allowing pathogens to continue spreading through infected individuals.

Plague Inc. simulates countries with different climates and latitudes. In addition, as the game progresses, vaccines will appear to prevent players from winning. Therefore, players have to use their abilities to influence the pathogen’s temperature and drug resistance, as shown in Figure 5.

---

**Figure 2.** Screenshot of Plague Inc.

**Figure 3.** Screenshot of Plague Inc.: disease transmission.
Data Analysis

Based on the normality test, this study used nonparametric statistics, the Mann–Whitney U test, and the Kruskal–Wallis test to verify the KAP of COVID-19 to understand whether the KAP of COVID-19 was affected by gaming experience. In addition, we used the chi-square test to analyze whether there is a significant difference between whether participants have played Plague Inc. and their demographic characteristics and the Spearman rank correlation test to analyze the correlation between gameful experience and COVID-19 KAP.

In this study, the Cronbach \( \alpha \) test was used to detect the internal consistency of the KAP of COVID-19 questionnaire and the gameful experience scale. For the KAP of COVID-19 questionnaire, Cronbach \( \alpha = 0.82 \), while Cronbach \( \alpha = 0.994 \) for the gameful experience scale; the results had acceptable internal consistency [39].

Results

A total of 486 participants were recruited for this study; demographic characteristics are shown in Table 2. Participants included 200 (41.2%) women and 286 (58.8%) men. The majority of participants were aged 20-29 years (n=323, 66.5%), had a university degree (n=305, 62.8%), were living with others (n=365, 75.1%), and were part of the labor force (n=335, 68.9%).

In total, 276 (56.8%) participants indicated they have played Plague Inc. and 210 (43.2%) have never played the game (Table 3).
Table 2. Demographic characteristics (N=486).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Participants, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>286 (58.8)</td>
</tr>
<tr>
<td>Female</td>
<td>200 (41.2)</td>
</tr>
<tr>
<td>Age group (years)</td>
<td></td>
</tr>
<tr>
<td>20-29</td>
<td>323 (66.5)</td>
</tr>
<tr>
<td>30-39</td>
<td>127 (26.1)</td>
</tr>
<tr>
<td>40-49</td>
<td>32 (6.6)</td>
</tr>
<tr>
<td>≥50</td>
<td>4 (0.8)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>High school or below</td>
<td>20 (4.1)</td>
</tr>
<tr>
<td>University</td>
<td>305 (62.8)</td>
</tr>
<tr>
<td>Graduate school</td>
<td>161 (33.1)</td>
</tr>
<tr>
<td>Living arrangement</td>
<td></td>
</tr>
<tr>
<td>Alone</td>
<td>121 (24.9)</td>
</tr>
<tr>
<td>With others</td>
<td>365 (75.1)</td>
</tr>
<tr>
<td>Occupation</td>
<td></td>
</tr>
<tr>
<td>Labor force</td>
<td>335 (68.9)</td>
</tr>
<tr>
<td>Non–labor force</td>
<td>103 (21.2)</td>
</tr>
<tr>
<td>Unemployed</td>
<td>48 (9.9)</td>
</tr>
</tbody>
</table>

Table 3. Descriptive statistics regarding participants’ game experience (N=486).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Participants, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ever played</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>276 (56.8)</td>
</tr>
<tr>
<td>No</td>
<td>210 (43.2)</td>
</tr>
<tr>
<td>Time since last played</td>
<td></td>
</tr>
<tr>
<td>&lt;1 week</td>
<td>26 (5.3)</td>
</tr>
<tr>
<td>&lt;1 month</td>
<td>63 (13)</td>
</tr>
<tr>
<td>&lt;6 months</td>
<td>83 (17.1)</td>
</tr>
<tr>
<td>&lt;1 year</td>
<td>25 (5.1)</td>
</tr>
<tr>
<td>≥1 year</td>
<td>79 (16.3)</td>
</tr>
<tr>
<td>Total playtime</td>
<td></td>
</tr>
<tr>
<td>&lt;1 hour</td>
<td>63 (13)</td>
</tr>
<tr>
<td>1-10 hours</td>
<td>127 (26.1)</td>
</tr>
<tr>
<td>≥10 hours</td>
<td>86 (17.7)</td>
</tr>
</tbody>
</table>

The chi-square test was used to examine whether there is a significant difference in the demographic characteristics of participants who have played Plague Inc. and those who have not. The analysis results are shown in Table 4.

The analysis results show significant differences in gender (P<.001) and age (P=.006) between participants who have and have not played Plague Inc. However, no significant difference is observed in education, living arrangement, or occupation.

In terms of gender, males who have played Plague Inc. account for a higher percentage (196/286, 68.5%) than those who have not (90/286, 31.5%), whereas more females have not played Plague Inc. (never played: 120/200, 60%; ever played: 80/200, 40%).

As for the different age groups, among participants aged 20-29 years, more have played Plague Inc. (195/323, 60.4%) than not (128/323, 39.6%); among those aged 30-39 years, more have
played (69/127, 54.3%) than not (58/127, 45.7%); among those aged 40-49 years, more have not played (20/32, 62.5%) than have played (12/32, 37.5%); and finally, among participants aged ≥50 years, none have played Plague Inc. before (4/4, 100%).

Table 4. Chi-square test for demographic characteristics between those who have or have not played Plague Inc. (N=486).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Participants, n</th>
<th>Ever played Plague Inc., n (%)</th>
<th>Chi-square test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes (n=276)</td>
<td>No (n=210)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>286</td>
<td>196 (68.5)</td>
<td>39 (1) .001</td>
</tr>
<tr>
<td>Female</td>
<td>200</td>
<td>80 (40)</td>
<td></td>
</tr>
<tr>
<td>Age group (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-29</td>
<td>323</td>
<td>195 (60.4)</td>
<td>12.1 (3) .006</td>
</tr>
<tr>
<td>30-39</td>
<td>127</td>
<td>69 (54.3)</td>
<td></td>
</tr>
<tr>
<td>40-49</td>
<td>32</td>
<td>12 (37.5)</td>
<td></td>
</tr>
<tr>
<td>≥50</td>
<td>4</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school or below</td>
<td>20</td>
<td>11 (55)</td>
<td>1.2 (2) .54</td>
</tr>
<tr>
<td>University</td>
<td>305</td>
<td>179 (58.7)</td>
<td></td>
</tr>
<tr>
<td>Graduate school</td>
<td>161</td>
<td>86 (53.4)</td>
<td></td>
</tr>
<tr>
<td>Living arrangement</td>
<td></td>
<td></td>
<td>1.8 (1) .18</td>
</tr>
<tr>
<td>Alone</td>
<td>121</td>
<td>75 (62)</td>
<td></td>
</tr>
<tr>
<td>With others</td>
<td>365</td>
<td>201 (55.1)</td>
<td></td>
</tr>
<tr>
<td>Occupation</td>
<td></td>
<td></td>
<td>3 (2) .22</td>
</tr>
<tr>
<td>Labor force</td>
<td>335</td>
<td>197 (58.8)</td>
<td></td>
</tr>
<tr>
<td>Non–labor force</td>
<td>103</td>
<td>57 (55.3)</td>
<td></td>
</tr>
<tr>
<td>Unemployed</td>
<td>48</td>
<td>22 (45.8)</td>
<td></td>
</tr>
</tbody>
</table>

The Mann-Whitney U and Kruskal-Wallis tests were used to assess any differences in KAP of COVID-19 between participants who had ever or never played Plague Inc., while the Kruskal-Wallis test was used to determine whether differences in KAP of COVID-19 were related to differences in time since last played and total playtime, as shown in Table 5.

There was a statistically significant difference between knowledge and attitude regarding COVID-19 for the item of whether a participant had ever played the game Plague Inc. The scores on questions related to knowledge of COVID-19 were lower among never-played participants (median 7, IQR 6-8) than among ever-played participants (median 7, IQR 7-8).

The scores on the questions related to knowledge of COVID-19 were lower among never-played participants (median 7, IQR 6-8) than among ever-played participants (median 7, IQR 7-8).

The scores on the questions about attitude regarding COVID-19 were lower among never-played participants (median 7, IQR 6-8) than among ever-played participants (median 8, IQR 7-8). The results indicated that there was a significant difference in scores on the questions about attitude regarding COVID-19 among participants with different total playtimes. The scores on questions about attitude regarding COVID-19 were lower among never-played participants (median 7, IQR 6-8) than among those with a total playtime of 1-10 hours (median 8, IQR 7-8).

Spearman rank correlation was used to examine the relationship between KAP of COVID-19 and gameful experience (Table 6). The results showed that there was a significant correlation between creative thinking ($\rho=.127, P=.04$) and dominance ($\rho=.122, P=.04$) in attitude; in addition, there was a significant correlation between creative thinking ($\rho=.126, P<.001$) and dominance ($\rho=.119, P=.049$) in practice.
Table 5. Mann-Whitney U test and Kruskal-Wallis test for determining the effect of game experience on knowledge, attitudes, and practices regarding COVID-19 (N=276).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Knowledge score</th>
<th>Attitude score</th>
<th>Practice score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (IQR)</td>
<td>Mean (SD)</td>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Ever played</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>7 (7-8)</td>
<td>7.31 (1.23)</td>
<td>8 (7-8)</td>
</tr>
<tr>
<td>No</td>
<td>7 (6-8)</td>
<td>7.07 (1.2)</td>
<td>7 (6-8)</td>
</tr>
<tr>
<td>Last played</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1 week</td>
<td>7.5 (7-8)</td>
<td>7.58 (0.99)</td>
<td>8 (7-8)</td>
</tr>
<tr>
<td>&lt;1 month</td>
<td>7 (7-8)</td>
<td>7.3 (1.24)</td>
<td>7.7 (7-8)</td>
</tr>
<tr>
<td>&gt;6 months</td>
<td>7 (6-8)</td>
<td>7.25 (1.4)</td>
<td>8 (7-8)</td>
</tr>
<tr>
<td>&lt;1 year</td>
<td>8 (7-8)</td>
<td>7.4 (1)</td>
<td>7 (6-8)</td>
</tr>
<tr>
<td>≥1 year</td>
<td>7 (6-8)</td>
<td>7.25 (1.16)</td>
<td>8 (7-9)</td>
</tr>
<tr>
<td>Total playtime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1 hour</td>
<td>7 (6-8)</td>
<td>7.27 (1.31)</td>
<td>7 (7-8)</td>
</tr>
<tr>
<td>1-10 hours</td>
<td>7 (6-8)</td>
<td>7.23 (1.31)</td>
<td>8 (7-8)</td>
</tr>
<tr>
<td>≥10 hours</td>
<td>8 (7-8)</td>
<td>7.45 (1.01)</td>
<td>7 (7-8)</td>
</tr>
</tbody>
</table>

Table 6. Spearman rank correlation of gameful experience with knowledge, attitudes, and practices regarding COVID-19 (N=324).

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>_a</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Attitude</td>
<td>.458b</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Practice</td>
<td>.087</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>.020</td>
<td>.034</td>
<td>.049</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Absorption</td>
<td>−.028</td>
<td>−.082</td>
<td>.031</td>
<td>.115</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Creative thinking</td>
<td>.029</td>
<td>.127c</td>
<td>.126c</td>
<td>.361b</td>
<td>.351b</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Activation</td>
<td>.076</td>
<td>.031</td>
<td>.052</td>
<td>.259b</td>
<td>.508b</td>
<td>.396b</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Absence of negative affect</td>
<td>.067</td>
<td>−.087</td>
<td>−.115</td>
<td>−.279b</td>
<td>.012</td>
<td>−.147c</td>
<td>.087</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Dominance</td>
<td>.003</td>
<td>.122c</td>
<td>.119c</td>
<td>.242b</td>
<td>.422b</td>
<td>.478b</td>
<td>.453b</td>
<td>−.141c</td>
<td>—</td>
</tr>
</tbody>
</table>

*aNot applicable.

bP<.01.

cP<.05.

Discussion

Principal Findings

This study determined the demographics of members of the public who have played Plague Inc. The results show that the research participants who have played Plague Inc. are mainly males aged 20-39 years. Studies in Spain and Turkey also found that gender indirectly affects game type preferences [40,41]. Research in the United States discovered that although the majority of middle-aged and older adults do not play video games, age does not affect their preference for strategic simulation games [42]. Participants who have played Plague Inc. displayed higher levels of knowledge and attitudes toward COVID-19. Health education implemented through gameful experience has been proven to effectively enhance knowledge of leptospirosis [43]. In addition, integrating gamified media into medical education courses has been shown to effectively improve knowledge and skill performance among nursing students [44-46]. Moreover, designing applications to integrate with gameful experience to explore learning performance in professional nursing education has also been proven to generate a higher level of knowledge when compared to traditional teaching methods [15]. In particular, research participants who had played Plague Inc. one year before the outbreak of the COVID-19 pandemic had higher attitude scores for COVID-19 than those who had not. Designing medical clinical instructional content as a serious game and incorporating gameful experience into training may...
effectively enhance medical knowledge and confidence among nursing students. Moreover, students may repeatedly practice in the simulated environment, and thereby develop a self-guided learning strategy [47,48]. China’s research on COVID-19–related serious games also confirmed that educational games result in better performance in learning retention than online lectures [49].

Participants who have played Plague Inc. indicated higher creative thinking and dominance during their gameful experience. Their attitudes and practices regarding COVID-19 have a significant positive correlation. In addition, the creative thinking involved in gameful experience is considered to be one of the significant factors that affect learning performance [50]. Gamified learning materials have been proven to stimulate creative thinking in learners and improve their attitudes and soft skills for school subjects [51]. Moreover, simulated situations can also cultivate creative thinking and indirectly improve attitudes toward public health [52,53].

The game environment of Plague Inc. allows players to repeatedly experiment with different pathogens and features. During this process, players gain a better understanding of how to enhance the infectivity and lethality of a pathogen. The challenge experiences and strategies accumulated through playing the game may indirectly improve the players’ corresponding attitudes and practices toward pathogens. Previous research has demonstrated that the reason that effective learning performance is achieved through serious games is due to the concept of experience-based learning. In addition, with game situations designed for players to repeatedly try and challenge, such games may motivate players to reflect on the content and strategize accordingly [54].

Limitations
This study has several limitations. First, the sample number may be insufficient to represent the general public of Taiwan. Second, as the survey was conducted on social networking websites, the surveys were mainly completed by males aged 20-39 years. This study lacks a broader scope of participants. Third, the research survey was conducted in May 2020; the COVID-19 pandemic was already easing in Taiwan by then. Moreover, the government and medical units had also implemented advocacy and educational messaging through multiple channels. As such, the public had developed a basic understanding of COVID-19. Fourth, as the game investigated in this study is a strategic simulation game, research participants may indirectly represent a specific group. Finally, Plague Inc. was not designed specifically for COVID-19. In addition, the goal of the game is to infect and kill all human beings. A new version of the game, The Cure, was launched on November 11, 2020, which allows players to promote antipandemic prevention and isolation measures by roleplaying as the World Health Organization; however, the public may still be unable to acquire precise knowledge of specific viruses via this game.

Future Research
This research focuses on the relationship between public KAP regarding COVID-19 and the gameful experience of Plague Inc. However, there may be more factors that affect public KAP regarding COVID-19 other than the gameful experience of Plague Inc. Therefore, further research is required to explore possible interactions with other dimensions [31].

Conclusions
This study has demonstrated that Plague Inc. provides pathogen simulation scenarios that allow players to continuously seek challenges. Members of the public who have played Plague Inc. exhibit higher levels of knowledge and attitudes regarding COVID-19. Moreover, the creative thinking and dominance developed in the gameful experience have been found to be correlated with attitudes and practices regarding COVID-19. Reinforcing creative thinking and dominance through serious games may be a valid approach. However, further verification is required.

Finally, it is imperative to heighten public awareness of the symptoms and transmission routes of COVID-19 amid the unprecedented crisis of the current pandemic. This study suggests that new media, such as games, should be employed to help the public accumulate learning experiences regarding pathogens and further establish public KAP toward pathogens. In this manner, the public may become more heedful of public health issues in the future.

Acknowledgments
We sincerely thank all the health care workers fighting COVID-19 and all participants of this study.

Authors’ Contributions
LHP dealt with conceptualization, funding acquisition, methodology, project administration, supervision, and writing (review and editing). MHB dealt with data curation, formal analysis, investigation, resources, validation, and writing the original draft. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest
None declared.

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Abbreviations

KAP: knowledge, attitudes, and practices
MERS-CoV: Middle East respiratory syndrome coronavirus
Current Competencies of Game Facilitators and Their Potential Optimization in Higher Education: Multimethod Study

Jannicke Baalsrud Hauge, PhD; Heinrich Söbke, PhD; Thomas Bröker, PhD; Theodore Lim, PhD; Angelo Marco Luccini, Dott Ing; Maksims Kornevs, PhD; Sebastiaan Meijer, PhD

Abstract

Background: Serious games can be a powerful learning tool in higher education. However, the literature indicates that the learning outcome in a serious game depends on the facilitators’ competencies. Although professional facilitators in commercial game-based training have undergone specific instruction, facilitators in higher education cannot rely on such formal instruction, as game facilitation is only an occasional part of their teaching activities.

Objective: This study aimed to address the actual competencies of occasional game facilitators and their perceived competency deficits.

Methods: Having many years of experience as professional and occasional facilitators, we (n=7) defined requirements for the occasional game facilitator using individual reflection and focus discussion. Based on these results, guided interviews were conducted with additional occasional game facilitators (n=4) to check and extend the requirements. Finally, a group of occasional game facilitators (n=30) answered an online questionnaire based on the results of the requirement analysis and existing competency models.

Results: Our review produced the following questions: Which competencies are needed by facilitators and what are their training needs? What do current training courses for occasional game facilitators in higher education look like? How do the competencies of occasional game facilitators differ from other competencies required in higher education? The key findings of our analysis are that a mix of managerial and technical competencies is required for facilitating serious games in higher educational contexts. Further, there is a limited or no general competence model for game facilitators, and casual game facilitators rarely undergo any specific, formal training.

Conclusions: The results identified the competencies that game facilitators require and a demand for specific formal training. Thus, the study contributes to the further development of a competency model for game facilitators and enhances the efficiency of serious games.

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KEYWORDS
facilitation; higher education; competency; simulation; gaming; educational games
Introduction

Games in education offer alternative means to balance the learning of a subject, along with its absorption, and application. Games used for nonentertainment purposes are often termed serious games [1-3]. However, there are also several other definitions and terms, including simulation games, educational games, or digital educational games [2], with the games being single player or multiplayer games. Furthermore, the usage in an educational setting differs, but within engineering education, these are often facilitated and based on experiential learning models. For instance, it might be assumed that a gameplay cycle reflects the 4 phases of Kolb's experiential learning cycle [4]: a recursive cycle of experiencing, reflecting, thinking, and acting to help learners increase their learning power.

Experiential learning, as well as gameplay, requires learners to take responsibility for their own learning. However, teachers should not overestimate the students' level of achievement in conceptual understanding [5]. A particular experience of an individual is often idiosyncratic to their perception of that experience and outside the control of the teacher. This dichotomy could encourage teachers to provide answers to students. However, the key is to avoid answers and instead develop the learners' capability to find answers on their own [4,6-8].

Purposeful learning processes based on serious games are often known as game-based learning (GBL). The learning outcomes supported with GBL are diverse. For example, meta-skills can be trained in simulation games [9,10], affective learning outcomes are achieved [11], engagement of the learner is increased [12], system interdependencies are demonstrated [13,14], and pure factual knowledge is taught [15,16], all based on GBL. De Gloria et al [17] distinguish between factual knowledge and skills as learning outcomes supported by GBL. Meanwhile, Egenfeldt-Nielsen [18] discusses a wide range of GBL scenarios and the learning outcomes achieved. In a systematic review on the use of serious games, Boyle et al [19] identify the categories of science, technology, engineering and mathematics; health; business and economics; and languages as domains for GBL. From the fundamental perspective of game studies, Klabbers [20] discusses the issues of knowledge building in games, while Shaffer has coined the term epistemic games [21]. Games can be seen as environments in which experiences are gained, which are processed by the learners, thus leading to learning processes. The theory of situated learning [22] is one of the approaches to understanding the nature of GBL: games may be seen as a context in which experiences may be gained. Another approach is that of sense-making [23]: the experiences generated by games must be interpreted and opened up by the learners themselves. Without an emphasis on any of these and other approaches, it becomes obvious that GBL poses different demands on the teacher compared to traditional teaching concepts, such as traditional classroom settings. Accordingly, the role of a teacher in GBL must differ from that of a traditional classroom setting. Here, the teacher as a facilitator can improve the permeance of learning by activating the affordances of GBL. Chapman et al [24] have outlined several characteristics to define experiential learning through games. Of these, the mixture of content and process (a balance between experiential activities and the underlying content or theory), the role of reflection (students gaining insight into themselves and their interactions), and meaningful relationships (getting students to see their learning in the context of the entire world) have direct contextual alignment to GBL. If properly facilitated, game-based learning has the potential to allow students to experience all 4 phases of Kolb's experiential learning cycle.

Facilitation should not be mistaken as a resource bank to help develop students’ confidence in the learning process. However, facilitators must set the right ambience where students feel engaged, valued, trusted, and respected [25]. They must create a space where students can express different viewpoints without a fear of saying the wrong thing, they must be sensitive to cultural experiences, and they must adapt the pace of learning while ensuring the learners understand and absorb the subject [24]. Students need to understand why they are doing something; otherwise, they may not reach the intended learning outcomes.

This paper asks where and what facilitation competency is necessary and to what extent competency models have been applied or administered by those who engage or use games in education. This kind of implementation (of facilitation competency and of competency model) might be somewhere in between facilitating collaborative knowledge building, and being aware of patterns in students’ learning behavior (as an individual and in a group) towards problem-solving. To better understand this relation, the mode of research could be reshaped to question the role of reflection with respect to the content through a facilitator’s ability to recognize students’ knowledge acquisition under guided and unguided independent learning; to apply knowledge building mechanisms into the GBL-process; and to differentiate between GBL and gamified learning, and other blended learning (including conventional) approaches. The overarching research examines a facilitator’s familiarity with competency models in GBL and whether this knowledge has any impact on pedagogy.

Consequently, an attempt has been made to assimilate the external and internal factors that are relevant to GBL, including the experience of the facilitator, the types of games used, the structure of the course, the level and size of cohorts, the equipment and technology used, and the environment. The autoethnography approach taken draws from our experiences and combines this with an advocacy and participatory approach aimed at understanding and acquiring new knowledge regarding the facilitation of GBL. The primary purpose of our study is to impart practical actions for future course design. What follows is a quantitative analysis to identify facilitator roles and to describe characteristics of facilitation (including models) that may be associated with successful GBL.

Our objective was to provide insights into the competency models for facilitators before conducting a self-observation and reflexive investigation into facilitating GBL. We then present and discuss the qualitative and quantitative analysis before concluding with some remarks on the facilitation process and associated competency models for GBL.
Methods

Our study attempted to assimilate the external and internal factors that apply to game facilitation, including the experience of the facilitator, the types of games used, the structure of the course, the level and size of cohorts, the equipment used, and the environment. Using an autoethnographic and participatory approach, we drew from our experiences to understand and acquire new knowledge on facilitating GBL, with a primary purpose to impart practical actions for future course design. A quantitative analysis followed to identify facilitator roles and to describe characteristics of facilitation (including models) that may be associated with successful GBL. The research questions to be answered were the following:

Which competencies are particularly needed by facilitators, and what are the training requirements for facilitators? What do current training courses for occasional game facilitators in higher education look like? How do the competencies of occasional game facilitators differ from other competencies required in higher education?

The study offers perspectives into competency models for facilitators from the literature (see Findings From the Literature Review subsection). We then conducted a self-observation and reflexive investigation on facilitating GBL (n=7; see Authors’ Experience Review subsection). The results were complemented by guided interviews with game facilitators from the field of engineering education (n=4; see External Experience Review subsection). The outcomes were compiled into a questionnaire with closed and open questions. The closed questions included an assessment of existing competency models for game facilitation–related activities. The questions determined the degree to which the competencies included in the models were considered important for game facilitation. Open questions aimed at contributing to a supplementation of the competency models. The questionnaire was distributed via social media. The qualitative and quantitative analyses of the answers (N=30) are presented (Questionnaire subsection) and discussed (see Discussion section) in this paper. We conclude with remarks on the facilitation process and associated competency models for GBL (see Summary and Future Work subsection).

Results

Findings From Literature Review

Competencies and their models have superseded the long-established job analysis and their resulting task descriptions in human resource management. For today’s fast-changing world and its complex situations, job analysis turned out to be an inefficient methodology [26]. Competency models define a structured collection of competencies that organizations can align to their objectives and strategies [27]. They support organizations to handle current and future situations [28] and “are used to hire, train, evaluate and promote employees on the same attributes” [27]. The primary perception of competency as the ability to deal with typical situations (as discussed by Mudra [29]) has meanwhile grown into the ability to deal with complex situations [28,30]. Boulter et al [31], cited in [32], suggested a process of 6 stages to define competency models: defining performance criteria, choosing a sample of people, collecting data, analyzing the data, validating the found results, and applying the model in practice.

From the rising complexity of situations and problems, the role of the facilitator has emerged to support organizations in the process of transition and transformation [33]. Expert consultants diagnose problems and prescribe a therapy, while facilitators are process consultants. Facilitators organize and release information in a methodical and interactive manner instead of focusing on the group’s output [34]. In this way, they improve a group’s effectiveness [35]: “the facilitator supports and guides, reassures and encourages […] and never ‘teaches’ the meaning of what is happening” [25].

Nelson and McFadzean [34] developed a conceptual competency model for facilitators and defined 7 of competencies: understanding context; technical, rational, interpersonal, task, and human process competencies; and other personal characteristics. These authors further differentiated these competencies into 3 levels, ranging from an initial to an expert facilitator. Stewart [33] generated a facilitator competency model from a qualitative study of groups in facilitation contexts and validated it through a survey. It comprises 5 areas of competencies: interpersonal competency (as communication and further skills), management process competency, knowledge competency, and personal characteristics.

In higher education, the role of a facilitator is just one role of several alternatives for teaching. In a literature review, Hoidn and Kärkkäinen [36] summarized instructional effectiveness and process–outcome research on competencies for effective higher education teaching. They concluded that effective teachers start their series of lessons with direct instruction and decrease control with the growing mastery of the students “to allow for independent and fluent performance by the students themselves”. However, they conclude that an ultimate consensus on effective teaching is difficult because of the manifold contexts of teaching and identify enthusiasm as a key element of instructional effectiveness. Blašková et al [37] proposed a competency model for university teachers based on theoretical analysis and a survey among students. The competency model they proposed comprises professional, educational, motivational, communicational, personal, science and research, and publication competency. Each competency is connected to indicators of positive and negative behavior. Both Blašková et al [37] and Hoidn and Kärkkäinen [36] emphasize the role of motivational competency.

In a similar concept involving the range between controlled lessons and independent performance of students, Leigh and Spindler [25] adopted the idea of closed and open games to develop competencies of simulation and game facilitators. The facilitators’ competencies range according to their degree of emotional detachment and the number of possible learning goals they allow. An observation from this study indicated that a facilitator’s preference on open or closed games was a product of learning preferences and personality type. Kortmann and Peters [38] proposed a competency model for game facilitation, identifying the differences between facilitating a simulation game and leading generic groups. They point out that the
facilitation of games should require more competencies, as games can serve more aims. By interviews with a group of facilitation experts, they validated the model. However, the authors expressed concerns that competencies at a subconscious level might have been missed.

Kortmann and Peters [38] identified similar competencies between facilitating game and leading generic group sessions, but they also indicated some dissimilarities, suggesting that game facilitators may require additional competencies. Taken together, the literature suggests that participants of games play within a model that requires game facilitators to have additional abilities. Game facilitators have to be aware that games are a means of learning about real-life situations and thus need to switch and adapt quickly to different roles and styles during gameplay. To facilitate a session and delegate control to the game environment, they have to comprehend the game as an immersive instrument and understand its elements and mechanics. Finally, facilitators have to translate between the game environment and reality so that the participants transfer their experiences to the real world and back [38].

Authors’ Experience Review

This section synthesizes our experiences as game facilitators (the author group). We reflected individually and independently upon a set of questions organized in 3 blocks: (1) experience with game facilitation, (2) knowledge on competency models, and (3) required competencies and the biggest discrepancy perceived between required and present competency.

The following information was collected to understand our experience with game facilitation: types of games used, number of games used, description of the educational settings for using the games, reasons for using games in teaching, changes in our perspective towards teaching, changes of our attitudes towards teaching, changes over time in the facilitation, and if we applied GBL in different settings.

The analysis shows that the group had extensive experience with facilitation. All but one participant had facilitated several games, a few had done so for decades, and all had done so for at least 4 years. Most of the group facilitated games within engineering or management studies at undergraduate and postgraduate level. Both fields have a strong tradition of using experiential learning [39,40]. In addition, 5 of the participants also facilitated games on an executive and vocational level.

We found that our group had played a large variety of games, had designed and developed games, and had used games developed by others. The games comprised multiplayer games, and both board or haptic games and digital games. The topics addressed in the games could be divided into managerial competency development and engineering topics, like bridge construction, sustainable manufacturing, and product development. Specific games addressing well-known problems, such as the bullwhip effect and capacity constraints (i.e., where the player learns about consequences of a decision and strategies for solving a problem) were applied, as well as games addressing communication, cooperation, and team skills. A difference between graduate courses and undergraduate courses became apparent. At the undergraduate level, the focus is on factual and procedural knowledge reflection. At the master level, it is on developing new knowledge and higher-order thinking. This is in line with how universities structure their undergraduate and postgraduate studies and with current taxonomies of learning objectives [41].

Although we have many years of experience in facilitating games, few of us had any formal pedagogical background when we began our careers as game facilitators. None of us could be classified as a professional facilitator. Even if we facilitated regularly, it was never the primary task of our work obligations. Only MK and SM had game facilitation and GBL as a formal part of previous education at the master’s level, and a few of us (SM, MK, and JBH) had aspects of GBL as a part of their PhD studies.

We were expected to be familiar with competency models—either explicitly or implicitly; information collected was from a general, teaching, and facilitation perspective. We asked ourselves whether we ever felt the need for a formal competency model during our game facilitation activities.

Our overall knowledge about competency models was inhomogeneous: 3 of us (AML, JBH, TB) neither knew of any models nor missed their absence, while 4 (HS, SM, TL, MK) had a general understanding or awareness of competency models. Various competency models were listed, but all were more relevant for higher education and vocational training [42-45]. One author (AML) pointed out that most studies on facilitation only cover small groups (fewer than 100 participants). We did not specifically feel that a formal competency model was lacking. Except for 2 (MK and JBH) people, we never felt a need for a formal competency model.

All agreed that a formal competency model might be useful when changing and adapting guidelines for game facilitation. Two authors commented that facilitation of highly customized and user-specific games is not supported by existing competency models. The collected data indicate that the roles of the facilitator change depending on whether the facilitator handles the whole teaching unit or only manages the game facilitation.

Regarding which competencies the authors felt were required, 2 further questions were asked: (1) Which competencies are important for the successful use of games from your point of view? (2) For which competencies do you see the biggest discrepancies between requirements and actual competencies? Where is there a need for training?

Most of us explained that we had little pedagogical knowledge when we started facilitating games (and teaching in general). The general consensus was to have the following competencies: “active listening”, as with “reactive” and “proactive abilities” to act on group reactions using strategies like “team management,” “participation techniques,” “consensus techniques,” “community management empathy,” “conflict resolution,” and “flexibility”; “ability to assess pure facilitation techniques,” “community management empathy,” “conflict resolution,” “flexibility,” “tolerating” and “proactive abilities.”

Several authors (AM, TL, SM, MK, and JBH) had aspects of GBL as a part of their PhD studies. Only MK and SM had game facilitation and GBL as a formal part of previous education at the master’s level, and a few of us (SM, MK, and JBH) had aspects of GBL as a part of their PhD studies.

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These led us to identify the following challenges: digital skills, leadership capabilities, cognitive science, and motivational skills.

Another major issue which was discussed was the preference for the facilitator to ask closed questions. In higher education, it is important to have learners synthesize and create new knowledge. Many students lack this ability; however, the games are often designed for this purpose. Facilitators need to have skills to encourage perspective taking and reasoning to foster this process. Regarding the facilitation of large groups, there are many digital tools that can support such facilitation. One hypothesis, based on our reflection in discussions, is that increased digital competencies among teachers and students could ease the use of these tools. As this has to be considered as a relevant topic, more information on tools and methods can be found in Multimedia Appendix 1.

Our collective experience as authors is, as stated earlier, in engineering and management in higher education, mostly at the university level. This is limited when analyzing the overall field of facilitation in higher education. Hence, additional data were collected from a wider audience through structured interviews and an online survey.

External Experience Review

This section analyses the experiences of 4 interviewees. The results were compared to the results of the author group (using the same questions) and the survey outcome. The 4 participants teach at different faculties, but all within engineering. Their experience in game facilitation ranged between 3 to over 10 years. All had been heavily involved in the development process of at least one game. This differed from the author group, whose members had been additionally involved in the development of commercial off-the-shelf games. The topics the interviewees taught were urban mobility planning, traffic simulation, health care logistics, and games for ideation and innovation.

One facilitator used the same game twice in a course. The game was integrated into an existing curriculum and used at the beginning and at the end of the course in a workshop setting with undergraduate and graduate students, so that the students could experience the learning progress throughout the course. Another facilitator used the same game throughout the semester with graduate engineering students, deployed through a blended learning environment. The curriculum was based on (and constructed around) the game scenarios. The third facilitator had used the game in around 25 sessions. It was embedded in a course, similar to the experience of the first facilitator and was played in one room with a physical and a digital component. The fourth facilitator used a game in a workshop setting (half a day) for undergraduate students in civil engineering. It was a blended learning concept (as in the second case), comprising briefing, playing, and lecture. In all 4 cases, the usage of games was initiated because of research activities and all chairs having extensive experience in GBL. All 4 facilitators had at least 2 years of experience in facilitating games. They agreed that games can be motivating and deliver a different way of teaching. One emphasized the interactive and active learning activities in GBL.

Regarding the perspective on facilitation, the 2 participants with more extensive experience in facilitating explained more and paid more attention to the introductory setting than the participants with less experience. One interviewee reported that the game can lead to frustration, but also to high engagement. However, overall, interviewee knowledge about competency models was limited: 2 participants professed to having no knowledge of the models, 1 had a general understanding, and 1 knew about the different competency models but not related to teaching. None had ever used a competency model for facilitation. However, 3 stated to have overlooked or at least missed it. Before gathering their own experience with game facilitation, they would have liked to be more aware of the following: connection between game design and facilitation process; how to observe and what to observe; how to assess and conclude the game process; how to know what aspects or knowledge needs to be assessed; how to understand the players’ game decisions, “soft data” as behavior of players, the level of communication with others etc; and how to observe learners in relation to providing feedback.

The final interview questions focused on the competencies the interviewees felt were required and on the gap. All interviewees mentioned the importance of knowing the subject, the tools used, and the technical environment as a required competency. One pointed out that it is imperative to also understand the methods behind GBL and that connecting gameplay and the intended learning outcome is a key success factor. Two of the interviewees mentioned the need for motivational competency. Three saw the necessity for a facilitator to integrate the game in a larger context from a didactical perspective. One interviewee mentioned the ability to respect and regard the competency of the students.

The answers concerning the gap focused on the lack of formal pedagogical courses on game didactics and how to integrate games into the curriculum. The interviewees also saw a deficiency in competency for facilitating groups of extreme sizes (ie, fewer than 4 or over 100 students) and how to deal with a group’s inhomogeneity in relation to the game runtime and different levels of knowledge. Further, 1 interviewee mentioned a dearth of methods for nurturing the reflection competency among the students during the game session and in the debriefing phase.

The results of the qualitatively analysis indicated a large uniformity related to facilitation and on the perception of required competencies. In order to obtain quantifiable data and a broader data source, an online survey was designed.

Questionnaire

This section describes the development of the questionnaire and its results. The questionnaire supplemented and refined the qualitative data with quantitative data on facilitation and competencies. The questionnaire was drafted by JBH, HS, and TB. It was followed by a pretest and a subsequent discussion among all authors to validate it. The questionnaire comprised 5 parts: (1) demographic data, (2) general questions on game facilitation, (3) questions on the most challenging game facilitation, (4) a section on the importance of a competency model, and (5) personal training received. The questionnaire
concluded with an open question for comment on any other important topic.

The questionnaire was distributed via social media in the authors’ personal networks and professional communities between June 1, 2020, and June 13, 2020, with 30 participants taking part in the survey. In the remainder of this section, the results specifically relevant for facilitating are described. Further results are included in Multimedia Appendix 2.

**Demographics**

The participants’ teaching experience in higher education ranged from 2-30 years, with an average of 12.5 years (SD 7.02). There was an average of 9.3 years of game facilitation experience (SD 6.73; range 1-30). In addition, the participants stated that they had facilitated an average of 12.2 (SD 20.32) games. Here, the span was wide, ranging from 1 to 100, with 1 value (999) being considered an outlier. As most participants had facilitated more than one game, this percentage differs from the percentage of educational scenarios. In terms of positions, 37% (11/30) of participants, the largest group, were professors and senior lecturers, 23% (7/30) were senior academics, 23% (7/30) were other academics, 13% (4/30) were PhD students, and the remaining 3% (1/30) included other positions.

When asked about the rationale for the use of games (with multiple selections being permitted), 83% (25/30) of participants indicated their own personal initiative, 67% (20/30) responded that a game was the best fit for the intended learning outcomes, 57% (17/30) used games to contribute to multifaceted teaching methods, 30% (9/30) of the participants stated that the game was available at the respective institution, and only 13.3% (4/30) of the participants used games because games were part of the curriculum. Overall, it can be stated that the games in higher education are not systematically anchored and are rather used because of the personal initiative of the lecturers.

Game facilitation comprises various roles. Thus, the participants were asked to rank 6 predefined roles taken during facilitation. For determining the statistical parameters, nonranked roles were given the value 7. Figure 1 shows that the role of the facilitator (average rank 2.3) and the role of the moderator (average rank 2.6) were considered the most important. The role of the instructor, which was ranked third (average rank 3.6), was followed by the mentor role (average rank 4.1). The presenter role (average rank 4.8) and the referee role (average rank 4.9) occupied the last 2 ranks. Overall, the results show a coherent picture of the importance of the different roles of a game facilitator. Table 1 shows the distribution of game types facilitated by participants.

![Figure 1. Ranked roles in game facilitating (7-point Likert scale; N=30).](image-url)
Table 1. Game types facilitated (multiple selections per respondent; N=30).

<table>
<thead>
<tr>
<th>Game type</th>
<th>Frequency, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specially developed serious games</td>
<td>22 (73)</td>
</tr>
<tr>
<td>Analogue games (eg, board games)</td>
<td>18 (60)</td>
</tr>
<tr>
<td>Analogue simulation games</td>
<td>14 (47)</td>
</tr>
<tr>
<td>Blended serious games (ie online and offline and/or digital and analogue)</td>
<td>14 (47)</td>
</tr>
<tr>
<td>Off-the-shelf games</td>
<td>13 (43)</td>
</tr>
<tr>
<td>Commercial entertainment games</td>
<td>12 (40)</td>
</tr>
<tr>
<td>“Modded” commercial entertainment games (ie, technically adapted)</td>
<td>6 (20)</td>
</tr>
<tr>
<td>Other</td>
<td>3 (10)</td>
</tr>
</tbody>
</table>

**Challenges in Game Facilitation**

With an open-ended question, the participants were requested to describe their most challenging game facilitation and to specify the challenges they faced. Using theme analysis, we identified 32 challenges from 18 of the answers. With each challenge being unique, they were clustered into groups based on common themes and shared characteristics. For example, some participants mentioned that players do not have sufficient knowledge or that players cheat. Although these examples are different, they still describe the characteristics or behavior of players. Hence, to ease the understanding of all challenges in game facilitation, they were grouped into 6 clusters: challenges related to (1) individual players and their actions, (2) technical aspects of using games, (3) class and collective aspects of players, (4) learning aspects of games, (5) games themselves, and (6) facilitators. Figure 2 shows these groups and challenges. The inner circle shows the clustered challenges and the outer circle the challenges themselves.

**Figure 2.** Cluster diagram of challenges in game facilitation as elicited by open-ended questions (N=18).
Challenges related to players include lack of knowledge to make all required decisions in a game. An example here might be a game for urban planning where students lack knowledge associated to economic aspects related to planning decisions. Furthermore, some students may not consider a game as a serious pedagogical tool. Convincing students to engage in game activities is challenging even without the added difficulty of students not fulfilling their role in the game.

Some challenges are technical in the context of digital games. Issues with software, device compatibility, or bugs or glitches in the game itself can be highly disruptive. Another challenge is student accessibility to computers or the internet to participate in a game.

Cohort sizes cause additional challenges on implementing games for learning, as discussed in the External Experience Review subsection and in Multimedia Appendix 1. A further issue is maintaining motivation for all players by ensuring the right environment during the entire game process. Mixed groups, in terms of skills, interests, and motivation can also be a challenge to the game facilitator.

As the purpose of games for learning is to ensure certain learning outcomes, converting the experiences of playing a game into these outcomes remains another major challenge. A concern mentioned by participants is that many students do not recognize the link between games and the subject of the overall program. Therefore, finding a proper balance between engagement and learning is a necessity. Immersion is important, but too high a level may hinder the learning effects.

Difficulties related to gameplay have implications for learning. The learning curve with respect to the game’s usage and interaction can add additional complexity into a game learning experience. However, overly simple games may be boring and insufficient to achieving learning outcomes, while overcomplicated games may be too hard, not engaging, and may distract from intended learning outcomes.

Finally, some challenges are related to the facilitators themselves. Situations where a facilitator does not detect cognitive biases in individual and collaborative activities would consequently lead to an incorrect assessment of the game experience. Facilitating a game where experts are present can be a challenge too, because of the demand to define the problem and solutions. The latter challenges relate directly to game facilitation and reflect the competencies required of game facilitators. The challenges in the other categories in Figure 1 were reported by game facilitators to be of lower priority for game facilitation (Table 2). Many of the challenges may be not relevant during the facilitation itself, but become more pertinent when preparing the GBL activity and the infrastructure required. Thus, further expertise might be necessary, including, for example, when managing technical problems, such as licenses or access to computers, or when grappling with game-related challenges, such as high complexity or long instructions. Overall, the challenges outlined above suggest that successful use of GBL depends on good game facilitation, but also on many other aspects. The following section examines what training game facilitators receive to master these challenges.
Table 2. Prioritization of competencies (5-point Likert scale; N=30).

<table>
<thead>
<tr>
<th>Competency</th>
<th>Stewart(^a) (mean)</th>
<th>Study (mean)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interpersonal competencies (communication skills)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbal</td>
<td>4.9</td>
<td>4.5</td>
<td>-0.4</td>
</tr>
<tr>
<td>Nonverbal</td>
<td>4.6</td>
<td>3.4</td>
<td>-1.2</td>
</tr>
<tr>
<td>Written</td>
<td>4.2</td>
<td>3.2</td>
<td>-1.0</td>
</tr>
<tr>
<td>Questioning</td>
<td>4.8</td>
<td>4.2</td>
<td>-0.6</td>
</tr>
<tr>
<td>Active listening</td>
<td>4.8</td>
<td>4.2</td>
<td>-0.6</td>
</tr>
<tr>
<td>Perceptive listening</td>
<td>4.6</td>
<td>4.1</td>
<td>-0.5</td>
</tr>
<tr>
<td>Empathy</td>
<td>4.3</td>
<td>4.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>Summarizing/paraphrasing</td>
<td>4.6</td>
<td>3.9</td>
<td>-0.7</td>
</tr>
<tr>
<td>Sensitivity to group</td>
<td>4.6</td>
<td>4.3</td>
<td>-0.3</td>
</tr>
<tr>
<td><strong>Interpersonal competencies (further skills)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity to underlying emotions</td>
<td>4.5</td>
<td>3.9</td>
<td>-0.6</td>
</tr>
<tr>
<td>Cultural awareness</td>
<td>4.5</td>
<td>3.8</td>
<td>-0.7</td>
</tr>
<tr>
<td>Encouragement of participation</td>
<td>4.4</td>
<td>4.3</td>
<td>-0.1</td>
</tr>
<tr>
<td>Negotiation skills</td>
<td>4.5</td>
<td>3.5</td>
<td>-1.0</td>
</tr>
<tr>
<td>Flexibility</td>
<td>4.8</td>
<td>4.3</td>
<td>-0.5</td>
</tr>
<tr>
<td>Conflict recognition</td>
<td>4.5</td>
<td>4.0</td>
<td>-0.5</td>
</tr>
<tr>
<td>Conflict resolution</td>
<td>4.3</td>
<td>3.7</td>
<td>-0.6</td>
</tr>
<tr>
<td>Conflict transformation</td>
<td>4.2</td>
<td>3.6</td>
<td>-0.6</td>
</tr>
<tr>
<td>Leadership</td>
<td>4.1</td>
<td>3.7</td>
<td>-0.4</td>
</tr>
<tr>
<td>Motivating others to achieve goals(^b)</td>
<td>4.0</td>
<td>4.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Motivating others to participate creatively</td>
<td>4.2</td>
<td>4.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Recognizing/rewarding achievement</td>
<td>3.5</td>
<td>4.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Model neutrality</td>
<td>4.6</td>
<td>3.8</td>
<td>-0.8</td>
</tr>
<tr>
<td>Building relationships</td>
<td>4.3</td>
<td>3.9</td>
<td>-0.4</td>
</tr>
<tr>
<td><strong>Management process competencies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning/organizing</td>
<td>4.4</td>
<td>4.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Managing time</td>
<td>4.5</td>
<td>4.3</td>
<td>-0.2</td>
</tr>
<tr>
<td>Managing audiovisual aids</td>
<td>4.4</td>
<td>3.5</td>
<td>-0.9</td>
</tr>
<tr>
<td>Managing physical environment</td>
<td>4.4</td>
<td>3.4</td>
<td>-1.0</td>
</tr>
<tr>
<td>Assimilating information</td>
<td>4.1</td>
<td>3.8</td>
<td>-0.3</td>
</tr>
<tr>
<td>Coaching others</td>
<td>3.8</td>
<td>3.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Managing feedback</td>
<td>4.4</td>
<td>4.3</td>
<td>-0.1</td>
</tr>
<tr>
<td>Managing contract</td>
<td>4.1</td>
<td>3.2</td>
<td>-0.9</td>
</tr>
<tr>
<td><strong>Understanding context competencies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding organizational context</td>
<td>4.4</td>
<td>4.0</td>
<td>-0.4</td>
</tr>
<tr>
<td>Knowledge of theory and application of group facilitation</td>
<td>4.1</td>
<td>3.9</td>
<td>-0.2</td>
</tr>
<tr>
<td><strong>Personal characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptability</td>
<td>4.7</td>
<td>4.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>Intellectual agility</td>
<td>4.5</td>
<td>4.3</td>
<td>-0.2</td>
</tr>
<tr>
<td>Trustworthiness</td>
<td>4.6</td>
<td>4.1</td>
<td>-0.5</td>
</tr>
</tbody>
</table>
Facilitation Training

The participants surveyed were also asked about the facilitation training they received (Table 3): 87% (26/30) selected “Learning by doing”, 57% (17/30) selected “Co-facilitating with colleagues”, and 47% (14/30) selected “Work shadowing with colleagues”. It is worth noting that 2 of the 3 responses (“Learning by doing” and “Co-facilitation with colleagues”) cannot be considered structured training and only a third of the participants received formal training (“Formal course in university pedagogy”). “Supervision by experienced colleagues” was mentioned by only a quarter of the participants, with supplier-specific training accounting for the remaining portion of replies. Overall, the proportion of those with formal training was rather low. This low rate of formal training may reflect the overall low rate of structured pedagogical training in university teaching.

Table 3. Types of training received (multiple selections per respondent; N=30).

<table>
<thead>
<tr>
<th>Type of training</th>
<th>Frequency, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning by doing</td>
<td>26 (87)</td>
</tr>
<tr>
<td>Co-facilitating with colleagues</td>
<td>17 (57)</td>
</tr>
<tr>
<td>Work shadowing with colleagues</td>
<td>14 (47)</td>
</tr>
<tr>
<td>Formal course in university pedagogy</td>
<td>10 (33)</td>
</tr>
<tr>
<td>Supervision by experienced colleagues</td>
<td>8 (27)</td>
</tr>
<tr>
<td>Training course at the supplier or third party institution</td>
<td>7 (23)</td>
</tr>
<tr>
<td>None</td>
<td>2 (7)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (3)</td>
</tr>
</tbody>
</table>
Figure 3. Helpfulness of trainings for categories according to Heron [46] (7-point Likert scale; N=27).

Competency Model

Stewart’s [33] competency model for group facilitators comprises 41 competencies categorized in 5 groups. The competence model was selected because group facilitation is usually included in game facilitation. Thus, Stewart’s model represents a valid initial foundation for further tailoring to game facilitation processes, as similarly concluded by Kortmann and Peters [38]. In this study, the participants were asked to rate the importance of each of the competencies for game facilitators on 5-point Likert scales (Table 2). Almost without exception, game facilitator competencies received lower scores for the importance of each competency.

Table 4 lists all competency group scores of the participants surveyed. The difference of 0.7 points for the group of communication skills as the most important competency group for group facilitation, is striking. For game facilitation covered by this study, all scores are in the narrow range of 3.9 to 4.0 and below the scores for group facilitation investigated by Stewart [33]. Potentially, games being in the focus of GBL activities act as compensating media, which require less competence from game facilitators than is necessary for group facilitators.

On average, the competencies of Stewart’s model [33] received for game facilitation scored 0.5 points lower compared to group facilitation. To determine which competencies were important for game facilitation compared to group facilitation, only competencies which scored higher for game facilitation over group facilitation were selected (Table 2, italics). The most significant competence was recognizing/rewarding achievement” with a difference of 0.6, indicating a typical characteristic of games: recognition and rewards. In second with a difference of 0.2 was motivating others to participate creatively, which is associated with games where motivation plays a prominent role. Competencies with a difference of 0.1 included motivating others to achieve goals. Finally, coaching others and planning/organizing were considered by the respondents more important for game facilitation over group facilitation.

Table 4. Difference of prioritization compared to Stewart [33] per competency group.

<table>
<thead>
<tr>
<th>Competency group</th>
<th>Stewart&lt;sup&gt;a&lt;/sup&gt; (mean)</th>
<th>Study (mean)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpersonal competencies (communication skills)</td>
<td>4.6</td>
<td>3.9</td>
<td>–0.7</td>
</tr>
<tr>
<td>Interpersonal competencies (further skills)</td>
<td>4.2</td>
<td>3.9</td>
<td>–0.3</td>
</tr>
<tr>
<td>Management process competencies</td>
<td>4.3</td>
<td>3.9</td>
<td>–0.4</td>
</tr>
<tr>
<td>Understanding context competencies</td>
<td>4.3</td>
<td>4.0</td>
<td>–0.3</td>
</tr>
<tr>
<td>Personal characteristics</td>
<td>4.5</td>
<td>4.0</td>
<td>–0.5</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values in this column are from the paper by Stewart [33].

Discussion

Study Outline

Over the past decades, there has been a shift from teacher-centric toward learner-centric learning models [47], which has also nurtured the uptake of experiential learning, including GBL. This shift has also affected the teacher’s role, but it remains unclear how this change has influenced the teacher’s competencies regarding facilitation within higher education. Teachers within higher education often lack the formal pedagogical education that teachers within the K12 system have. In this study, therefore, the following 3 research questions were investigated: (1) Which competencies are particularly needed by the facilitator, and what are the training needs of the facilitator? (2) What do the relevant training courses for occasional game facilitators in higher education look like? (3) How do the competencies of occasional game facilitators differ...
from the competencies needed for other learning approaches, such as lectures, problem-based Learning, or online education?

**Which Competencies Are Particularly Needed by the Facilitator, and What Are the Training Needs of the Facilitator?**

Core competencies according to the interviews and authors’ reflection were divided into 2 major groups: managerial and technical competencies. The more technical competencies comprise topics such as the knowledge of the gameplay, game content, its connection to the intended learning outcome, and the operation of any technical infrastructure. The more managerial competencies include active listening and reactive and proactive abilities to act on groups reactions, through the use of strategies like team management, leadership, motivational and participation techniques, consensus techniques, community management empathy, conflict resolution, and flexibility. This is underpinned by the survey (Table 2), which prioritized the competencies for game facilitation designated by Stewart [33]: verbal communication received a score 4.5 (out of 5), motivating others to participate creatively scored 4.4, and flexibility and encouraging participation (all interpersonal competencies) both scored 4.3. The personal characteristics adaptability and intellectual agility scored 4.6 and 4.3, respectively. Competencies like planning and organizing (score 4.5), and managing time and feedback (both scores 4.3) were also seen as core competencies, which is in line with the qualitative results.

The second part of this research asked about the need for training. The answer to this was complicated by the low proportion of people who received training (formal and informal). Among the interviewees, none had formal pedagogical training. This holds for two-thirds (67%, 20/30; Table 2) of the survey group, while we seem to have a higher percentage of formal course completion (10/30, 33.3%; Table 2). This might be because more than half of us hold faculty positions with requirements on pedagogical training for higher education. The qualitative results clearly state the need for training in the connection of the pedagogy and gameplay from a different perspective.

The actual training in the area of game facilitation for all was low, which can be seen also in the following wish list of the interviewees on the addressed training topics before first facilitation: connection between game design and facilitation process (Heron: meaning); how to observe and what to observe (Heron: meaning); how to assess and conclude the game process; how to know what aspects of knowledge need to be assessed (Heron: planning and structuring); how to holistically understand players’ game decisions and “soft data” as representations of player behavior, and the level of communication with others (Heron: confronting and feeling); and how to observe players for feedback purposes.

According to Figure 3, training in general was perceived as helpful. Looking at the wish list, it becomes apparent that a training program focusing on facilitation would support the formal competency development and also fill a need identified by many of the respondents.

**What Do the Relevant Training Courses for Occasional Game Facilitators in Higher Education Look Like?**

The answer to this question was somewhat negative (Table 2). In the survey, 87% (26/30) indicated that their training consisted of learning by doing. In the author group, fewer than 20% (1/7) had received formal training before starting their game facilitation. Overall, the share of formal training remains low. Compared with K12 teachers or professional vocational trainers, this low rate of formal training may reflect the overall low rate of structured pedagogical training in university teaching. There is, however, a change in higher education. Although, scientific excellence used to play an overarching role in applying for academic faculty positions, there has been a shift toward also focusing on teaching experience and competency over the past decade. This may relate also to an increased focus on the process quality within higher education [48]. More and more countries have imposed formal requirements on pedagogical competencies, as a part of the appraisal procedure. Maturity models are widely used for assessing the maturity level within a specific area [49,50]. Despite not being frequently used, different maturity models also exist for higher education. For example, Zhou [51] has developed a capability maturity model of the e-learning process. Game facilitation is not primary about e-learning, as many games are haptic or board games, but Zhou includes the dimension of process capability in his model, which is transferable for game facilitation and higher education. It comprises the following levels (those transferrable from e-learning to GBL): delivery, delivers facilitated GBL units; planned, outlines clear and measurable objectives for GBL projects; defined, provides a defined process for development and support of GBL; managed, ensures the quality of the resources and the deliveries; and optimizing, continually improves in all aspects of the process. In matching the outcomes of the received training focusing on facilitation, it can be concluded that maturity is maximum at level 1 of the model proposed by Zhou [51]. This might also be a reason why the uptake is so low. Staff interested in using games for education must undergo a time-consuming process of learning by doing. This leads to difficulties in delivering an acceptable quality of teaching during the first years occupying this role. When we consider the fact that most facilitators only use these methods once or twice a year, it is easy to see why there might be a problem.

As there is arguably hardly any training for facilitation of games provided and an increasing number of universities are offering programs on didactics in higher education, it would be valuable to know how the participants in this study rate the differences in competency needs.

**How Do the Competencies Of Occasional Game Facilitators Differ From The Competencies Needed for Other Learning Approaches, Such as Lectures, Problem-Based Learning, or Online Education?**

Table 2 and Table 4 illustrate this issue. With reference to Stewart’s competency model, it can clearly be stated that the participants see large differences in quite a few areas. For communication skills, the overall tendency is that this is less important in the facilitation of games, where nonverbal and
written communication showed the highest difference (1.2 and 1.0, respectively), but is nonetheless still relevant. This might be seen in the light of the answer given to the question of what type of games the participants use: a large majority indicated that they use games with in-built communication. For interpersonal skills, there are also large deviations, specifically on negotiation (difference of 1.0); however, these skills might also considered part of the gameplay, and thus not so relevant for the facilitation. According to Table 2, the differences for competencies on motivation related to goal achievements, creative participation, and reward and recognition are quite low; however, there is a higher need for these competencies. These are also competencies that were identified on the wish list in the qualitative part of the study. On the other hand, personal characteristic competencies seem to be less needed.

Summary and Future Work

It can be concluded that the maturity of game facilitation in higher education is low. There is a need for formal training courses, with competency models rarely being implemented in this field. Besides implementing training for game facilitators, further approaches are available for increasing the diffusion of serious games and the effectiveness of GBL. Figure 2 provides an overview of the challenges involved—such as motivating players—to be covered by approaches for increasing the diffusion of serious games. For example, giving learners a choice to take part in GBL activities or to engage in some other learning activities is likely to increase learner motivation in the chosen learning activity [15,52]. Likewise, the choice of the game used itself has a great impact on learning success: learners have preferences for games depending on learner traits, such as age, ethnicity, and gender [53,54], but certain game mechanics might be especially suited for GBL activities [55,56].

This multimethod study investigated the competencies essential for game facilitation in higher education and analyzed, with use of empirical data, the perceived gap between essential and existing competencies. This paper also discusses if there is a structured approach for competency development for the target group. The findings indicate that there is a limited or no general competence model for game facilitators and that casual game facilitators rarely undergo any specific, formal training. The lack of specific training is to be regarded as one reason for the lack of dissemination of games in higher education. The study provides the basis for a competence model for game facilitators that may serve as a prerequisite for the development of specific trainings. Future work includes the confirmation, consolidation, and refinement of the competence model presented, for example, by means of an extended survey for a larger group of participants. Based on the competence model defined, we plan to develop organizational policies for training. With an increased dissemination of GBL provided by the growing of game facilitation competencies, the effects on teaching in higher education should be explored. However, one approach that could replace the training of game facilitators is the digital support or even the replacement of game facilitators by virtual assistants as supported by improvements in artificial intelligence [57].

Conflicts of Interest

None declared.

Multimedia Appendix 1
Facilitation with large groups.
[PDF File (Adobe PDF File), 48 KB - games_v9i2e25481_app1.pdf ]

Multimedia Appendix 2
Further results from the questionnaire: educational scenarios.
[PDF File (Adobe PDF File), 42 KB - games_v9i2e25481_app2.pdf ]

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**Abbreviations**

GBL: game-based learning
Mobile Game Design Guide to Improve Gaming Experience for the Middle-Aged and Older Adult Population: User-Centered Design Approach

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Abstract

Background: The number of older adult gamers who play mobile games is growing worldwide. Earlier studies have reported that digital games provide cognitive, physical, and socioemotional benefits for older adults. However, current mobile games that understand older adults’ gameplay experience and reflect their needs are very scarce. Furthermore, studies that have analyzed older adults’ game experience in a holistic manner are rare.

Objective: The purpose of this study was to suggest mobile game design guidelines for adults older than 50 years from a holistic gaming experience perspective. Adopting a human-centric approach, this study analyzes middle-aged and older adults’ gameplay experience and suggests practical design guides to increase accessibility and satisfaction.

Methods: We organized a living laboratory project called the “Intergenerational Play Workshop.” In this workshop, 40 middle-aged and older adults (mean age 66.75 years, age range 50-85 years) played commercial mobile games of various genres with young adult partners for 1 month (8 sessions). Using a convergent parallel mixed-method design, we conducted a qualitative analysis of dialogue, game diaries, and behavioral observations during the workshop and a quantitative analysis of the satisfaction level of the game elements for the mobile games that they played.

Results: This project was active from April 2019 to December 2021, and the data were collected at the workshops from July 1 to August 28, 2019. Based on the identified themes of positive and negative experiences from the qualitative data, we proposed 45 design guides under 3 categories: (1) cognitive and physical elements, (2) psychological and socioemotional elements, and (3) consumption contextual elements. Our empirical research could reaffirm the proposals from previous studies and provide new guidelines for improving the game design. In addition, we demonstrate how existing commercial games can be evaluated quantitatively by using the satisfaction level of each game’s elements and overall satisfaction level.

Conclusions: The final guidelines were presented to game designers to easily find related information and enhance the overall understanding of the game experience of middle-aged and older adults.

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KEYWORDS
mobile games; older adults; middle-aged adults; design guideline; gaming experience
**Introduction**

**Background**

The number of mobile game players has increased annually to 1.1 billion in 2017 and 1.5 billion in 2020. It is expected to increase by 50 million to 100 million people every year and to reach 1.8 billion by 2024 [1]. The rise of smartphone penetration [2] could give older adults an opportunity to easily access digital games. According to the American Association of Retired Persons research in 2019, 73% of game players aged 50 years and older use mobile devices in the United States—this proportion has increased from 57% in 2016, which was only a few years earlier. In contrast, the proportion of game players using computers and laptops decreased from 36% in 2016 to 47% in 2019 [3]. The Korean mobile game market for the older adult population is developing actively with high smartphone penetration rates and high Wi-Fi accessibility in public places. In a survey conducted in 2020, 52.1% of Koreans in their 50s and 31.9% of Koreans aged 60 to 65 years mentioned that they played mobile games [4]. Previous studies have reported various benefits of digital gameplay for older adults, including lower cognitive decline [5-7], increased physical activity [8-11], and improved socioemotional status [12-14]. However, most digital games cater to the younger generations, making it difficult for many older adults to play them [15,16]. In addition, game designers may not be sensitive to the gaming experience of older adults because most of them belong to the younger generation. Therefore, it is necessary to improve the game design based on the understanding of older adults’ needs, preference, and play experience. As the demand for mobile games is expected to increase among middle-aged and older adults in the future, this study aims to provide experience analysis and design guidelines focused on mobile games.

**Design Guide for Age-Related Changes**

Earlier studies have reported various factors that cause difficulties for older adults to play mobile games. In a survey of Canadian gamers aged over 55 years, the highest ranked difficulty was that the games were too complicated [17]. In addition, age-related limitations such as declining vision, hearing, cognition, and motor functions can cause difficulties in playing games [18]. Older adults who were skilled gamers did not experience many difficulties, but they complained of difficulty in changing game settings, small object size, time limit, understanding rules, and fast pace [16]. To improve the accessibility of digital technologies such as computers and the internet, many studies have suggested interface design guides for older adults, considering age-related changes such as vision, motor control, hearing, cognition, and so on [19-21]. Several attempts have been made to apply a similar approach to digital game design. Gamberini et al [22] studied age-related changes in terms of perception (vision, hearing, and touch/movement), attention, learning/memory, and cognitive tasks and proposed specific implications for game design. Fua et al [23] also studied the relationship between cognitive abilities and gameplay mechanics for older adults, especially within populations at risk of dementia. In addition, Ijselsteijn et al [24] provided insights into digital game design based on usability guides for older adults. Gerling et al [25] created structural models of gameplay and proposed guides that consider age-related changes under the categories of game elements, such as players and resources, user interface, core mechanics, and outcomes. However, these studies did not analyze the game experience of older adults through an empirical study. De Barros et al [26] improved their mobile game app by reflecting on older adults’ behavior and feedback, and they proposed recommendations under 3 categories, that is, navigation, interaction, and visual design.

**Design Guide Related to Psychological and Socioemotional Aspects**

Various surveys conducted in the United States, Canada, South Korea, and Flanders showed similar results regarding game preferences of older adults. They indicated that older adults strongly prefer puzzles, card/board games, and strategy games to other genres. These types of games are mostly casual and easy to learn and play, but are also challenging [4,12,27,28]. Other studies also showed that older adults prefer an intellectual challenge to fighting and racing games, which require skills related to speed and reflexes [29,30]. Another experimental study identified how the enjoyment of older adults differs depending on the genre of the games. It was found that puzzle games were easier to play and more enjoyable than simulation games or action games [31]. In addition, older adults’ preference for the game genre did not differ between gamers and nongamers [32]. Among the 6 motives of game play presented from the uses and gratifications perspective [33], challenge was the highest among older adults, followed by arousal, diversion, fantasy, competition, and social interaction [27]. In addition, older adults played digital games for relaxation, fun, and to pass time [16]. For older adults, the emphasis was not only on fun associated with games but also on personal growth and benefits as motivations to play [34]. In fact, many older adults described playing games as a means of exercising their brain [35].

De Carvalho and Ishitani [36] conducted an empirical study to test existing mobile puzzle games in older adults and proposed guidelines related to motivational aspects for serious games. Cota et al [37] also found the main features that motivate the older adults by analyzing their evaluations of mobile games developed by the researchers. Both studies proposed design guides to encourage motivation, such as usability heuristics, clear and motivational feedback, clarifying the benefits of gaming, cognitive training, and providing proper difficulty levels.

Older adults play games mostly alone rather than with others [27,28]. However, baby boomers are community-oriented, and social interaction is an important motivation for them [30]. Moreover, experimental studies have shown that playing with a partner leads to a higher enjoyment than playing with a computer [38,39]. In particular, middle-aged adults (40-59 years) are more likely to play games with their children [28]. In the United States, 57% of parents play games with their children at least once a week [40]. De Schutter and Vanden Abeele [41] recommended a game design that considered the psychosocial context of older adult players, which include finding the right playing partner, vicarious play, time management, sharing high scores, and balancing teams. Additionally, McLaughlin et al [42] conducted a qualitative study on the experience of older adults...
adults in terms of costs (e.g., initial frustration, stereotype threat, emotional arousal, usability challenges) and benefits (e.g., self-esteem, physical activity, social interaction, well-being, fun, learning). Marston [43] also analyzed older adults’ game experience empirically under a framework of 3 categories (older adults, technology, and content/interaction) and applied them to suggest design guidelines.

**Research Questions in This Study**

While many user experience studies have been conducted on digital apps for older adults, not many have considered “playability” for older adults on “mobile game” media. Furthermore, studies that have analyzed older adults’ gaming experience in a holistic manner are rare. Some studies have investigated the elements of age-related changes and suggested guides [23-25]. However, they were not empirical studies. Some empirical studies have analyzed the experience of older adults; however, they lacked suggestions for various game elements under the structural framework [36,37,42]. In addition, previous guides did not include consumer behavior contexts related to mobile gameplay, such as devices, installation, in-game payment, and advertising. Moreover, some empirical studies suggested guides under the structural framework, but they tested only limited devices or genres [43]. Therefore, the purpose of this study was to suggest practical design guides based on empirical studies for game designers, including various mobile game elements, from the holistic perspective of middle-aged and older adults’ gaming experience. Game elements can be considered as a set of building blocks or features shared by games [44]. We used “game elements” in a broad interpretation to connect user-perceived game elements to game design elements. This study was guided by the following 3 research questions (RQs):

- **RQ1.** What are the positive and negative experiences of middle-aged and older adults when playing mobile games?

- **RQ2.** What mobile game design guides should be considered to embrace middle-aged and older adults?

- **RQ3.** How satisfied are middle-aged and older adults with the game elements of commercial mobile games?

We planned to identify several themes of the gaming experience, design guidelines from qualitative analyses (RQ1 and RQ2), and provide useful indicators by presenting the satisfaction levels of the game elements in existing commercial games by using quantitative analysis (RQ3). This convergent parallel mixed-methods design [45] was used to identify important criteria that could affect the gaming experience of middle-aged and older adults and to determine how existing games can be evaluated based on these criteria.

**Methods**

**Participants**

We adopted a human-centered approach by using a living laboratory that promotes active involvement of users and applies their experience and feedback to the research [46]. We collaborated with 2 institutions that organize programs for middle-aged and older adults. One institution is the 50 plus campus that provides educational programs targeting adults in their 50s and 60s (middle-aged adult group) and the other institution is a senior welfare center targeting adults aged 65 or older (older adult group). We designed living laboratory activities where middle-aged and older adults played various genres of mobile games with young adult partners. During these activities, participants not only played games but also discussed their playing experiences and provided recommendations to improve game design. A total of 40 middle-aged and older adults participated, and Table 1 shows the demographic information of the participants.
Table 1. Demographic information of the participants (N=40).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), mean (SD)</td>
<td>66.75 (9.31)</td>
</tr>
<tr>
<td>Age range (years), n (%)</td>
<td></td>
</tr>
<tr>
<td>50-59</td>
<td>11 (28)</td>
</tr>
<tr>
<td>60-69</td>
<td>14 (35)</td>
</tr>
<tr>
<td>70-79</td>
<td>12 (30)</td>
</tr>
<tr>
<td>80-85</td>
<td>3 (8)</td>
</tr>
<tr>
<td>Location, n (%)</td>
<td></td>
</tr>
<tr>
<td>50 plus campus (middle-aged adult group)</td>
<td>20 (50)</td>
</tr>
<tr>
<td>Senior welfare center (older adult group)</td>
<td>20 (50)</td>
</tr>
<tr>
<td>Gender, n (%)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>30 (75)</td>
</tr>
<tr>
<td>Male</td>
<td>10 (25)</td>
</tr>
<tr>
<td>Job status, n (%)</td>
<td></td>
</tr>
<tr>
<td>Employed</td>
<td>12 (30)</td>
</tr>
<tr>
<td>Retired/homemaker</td>
<td>28 (70)</td>
</tr>
<tr>
<td>Education, n (%)</td>
<td></td>
</tr>
<tr>
<td>Elementary/middle school</td>
<td>13 (33)</td>
</tr>
<tr>
<td>High school</td>
<td>7 (18)</td>
</tr>
<tr>
<td>Undergraduate school</td>
<td>12 (30)</td>
</tr>
<tr>
<td>Graduate school</td>
<td>8 (20)</td>
</tr>
<tr>
<td>Monthly income(^a), n (%)</td>
<td></td>
</tr>
<tr>
<td>Low: Less than ₩2 million</td>
<td>18 (45)</td>
</tr>
<tr>
<td>Middle: ₩2-8 million</td>
<td>16 (40)</td>
</tr>
<tr>
<td>High: More than ₩8 million</td>
<td>5 (13)</td>
</tr>
<tr>
<td>No response</td>
<td>1 (3)</td>
</tr>
</tbody>
</table>

\(^a\)US $1=₩1200.

The recruitment process was conducted differently in both the places. Web-based recruitment was conducted at the 50 plus campus for a month, and 20 participants were recruited. Our orientation session explained the workshop activities and received informed consent forms for participation. Two participants did not attend the orientation, and one decided not to participate after the orientation. Therefore, we recruited 3 more participants. In the senior welfare center, offline recruitment was conducted for 1 month. Two social workers familiar with the members of the center participated in the recruitment and selected 20 mentally and physically healthy participants. We also held an orientation session and received informed consent forms. The recruitment results showed a high percentage of female participants. It can be assumed that this was because female members attending these 2 institutes tended to prefer new and coactivity programs over male members.

Ten participants were grouped in 1 class, and there were 4 classes in the workshops (2 middle-aged groups and 2 older adult groups). Over 8 sessions, the number of absent days per participant was 0-4 times (average attendance rate, 91.6% [293/320]). However, no participant dropped out during the workshops in both places. Ethical approval was obtained from the institutional review board of the authors’ institute. Table 2 shows the prior gaming experience of the participants. There were 13 older adult participants who reported as currently playing games because they had participated in an earlier program that included serious games for cognitive training at the senior welfare center. The age of the first gaming experience was widespread among the middle-aged adult group, and most of the older adult participants started playing games at an older age.
Table 2. Prior gaming experience of the participants.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Values, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Game experience (n=40)</strong></td>
<td></td>
</tr>
<tr>
<td>No gaming experience</td>
<td>12 (30)</td>
</tr>
<tr>
<td>Currently gaming</td>
<td>15 (38)</td>
</tr>
<tr>
<td>Have experience but no longer play</td>
<td>13 (33)</td>
</tr>
<tr>
<td><strong>Age of first playing games (years)a, (n=28)</strong></td>
<td></td>
</tr>
<tr>
<td>10-19</td>
<td>3 (11)</td>
</tr>
<tr>
<td>20-29</td>
<td>3 (11)</td>
</tr>
<tr>
<td>30-39</td>
<td>5 (18)</td>
</tr>
<tr>
<td>40-49</td>
<td>2 (7)</td>
</tr>
<tr>
<td>50-59</td>
<td>6 (21)</td>
</tr>
<tr>
<td>More than 60</td>
<td>9 (32)</td>
</tr>
</tbody>
</table>

*aOnly for participants with gaming experience.

In addition, 11 undergraduate students (9 females and 2 males, mean age 21.45 years) majoring in the Department of the Senior Industry at Kangnam University participated in the living laboratory activities as supporting partners. In each class, 1 young partner was paired with 1 older participant. Young partners participated in all 4 classes and supported a total of 4 older participants per person. The other young partners assisted in the workshop activities. We also held an orientation session for young adult partners to receive their informed consent for participation and provide instructions for the role of the supporting partners. They helped older participants play games, played games together, and received feedback from them through questions.

Games Played in the Workshops

Four graduate students studying game design and human-computer interaction developed the first list of games, which are popular and enjoyed across all age groups. They referred to the annual report of the popular game list and personal experience of playing with older adults. Each student added 20-60 game titles in various genres and platforms and scored the difficulty level of gameplay from 1 to 4 according to the time required to learn them (1: 10 minutes, 2: 1-2 hours, 3: a week, 4: more than a week). A total of 146 games were included in the list, and 3 authors finally selected 9 games to play during the workshops. Table 3 shows the games played in the workshops.

Table 3. Games played in the workshops.

<table>
<thead>
<tr>
<th>Title</th>
<th>Genre</th>
<th>Game description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Game played by both groups (age range, 50-85 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homescapes</td>
<td>Puzzle and story</td>
<td>A match-3 puzzle where the player solves puzzles presented with stories and decorates a house [47].</td>
</tr>
<tr>
<td>Fruit Ninja</td>
<td>Action</td>
<td>A fruit-slicing action game where the player swipes and slices fruits with a blade [48].</td>
</tr>
<tr>
<td>Long Journey of Life</td>
<td>Adventure and story</td>
<td>A story-based game where the player controls a small boat and sails through life stages from birth to death [49].</td>
</tr>
<tr>
<td><strong>Games played by the middle-aged group only (age range, 50-64 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brawl Stars</td>
<td>Action</td>
<td>A multiplayer web-based battle arena game where players attack other players with the same team members [50].</td>
</tr>
<tr>
<td>Sally’s Law</td>
<td>Action and story</td>
<td>A platformer action game with a story and puzzle [51].</td>
</tr>
<tr>
<td>Good Pizza, Great Pizza</td>
<td>Management</td>
<td>The player becomes the owner of a pizza restaurant and makes pizzas according to orders [52].</td>
</tr>
<tr>
<td><strong>Games played by the older adult group only (age range, 65-85 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word Tower-World Trip</td>
<td>Puzzle</td>
<td>A word puzzle game where the player swipes and connects syllables and finds hidden words [53].</td>
</tr>
<tr>
<td>Go-stop Plus</td>
<td>Web board</td>
<td>A web-based version of a Korean traditional card game that uses a deck of 48 cards [54].</td>
</tr>
<tr>
<td>Lonely One: Hole-in-one</td>
<td>Shooting and sports</td>
<td>A golf-based game where the player adjusts the parabola and releases to hit the ball [55].</td>
</tr>
</tbody>
</table>
The following guidelines were used to choose the games. First, the game should be accessible in both mobile phones and tablet personal computers; 72 games were selected in this stage. Second, the game should be in Korean language; 64 games were further selected in this stage. Third, to ensure that the games were not too complicated for older adults, the difficulty level should be 1 or 2. In this stage, 54 games were selected from the remaining ones. There were 21 puzzle games, 6 action games, 6 web board games, 4 adventure games, 10 management/simulation games, 6 shooting games, and 1 rhythm game. Before we finalized the list, we had discussions with a social worker and a program manager in each collaborating institution regarding participant groups’ digital skills [56] in using mobile apps. In addition, we had a pilot session to test the games with 13 participants from the 50 plus campus. Finally, we selected 1-3 games from each genre in order to have an even distribution from a variety of genres such as puzzle, action, web board, adventure, and management games. Considering the digital skills of each participant group, we selected 3 common games for both groups and 3 different games for each group. “Go-stop Plus” and “Lonely One: Hole-in-one” were selected for the older adults’ group because they are based on card games and sports, which are familiar to older adults in real life. Participants also played other games not in this list according to their preferences during the living laboratory activities and provided their feedbacks.

Workshop Procedure

We organized intergenerational play workshops twice a week for 4 weeks (8 sessions), and each session lasted 1-2 hours. Each session consisted of a short lecture (10-30 min), coplaying (20-40 min), survey and pair discussion (10-20 min), and group discussion (10-20 min). Figure 1 shows the workshop process.

The lectures dealt with how to play specific games and useful information to enhance the game literacy of those who are not familiar with digital games. After a short lecture, participants and young adult partners were paired, and they played games together. Each pair was provided a 10-inch tablet personal computer, but they could use their personal smartphone if they wanted. Young adult partners not only played games together but also taught participants how to play and get acquainted with the games. After playing a game, the young partner asked, “what were you satisfied with or unsatisfied with during the game play?”, to which the participants provided their responses. In addition, participants filled out the survey form by checking the satisfaction level for each element of the game. They discussed their gameplay experience and shared ideas of design recommendation during group discussions. Participants were compensated with ₩10,000 (approximately US $8) per session for participating in the workshops.

Figure 1. Photographs from the intergenerational play workshop.
For over one month of the living laboratory activities, older adult participants could visit the play room at the senior welfare center and use the tablet personal computers, which had the recommended games installed. There was no playroom at the 50 plus campus, but middle-aged adult participants could borrow the tablet personal computers and play games at home. Both groups could also install and play games on their personal mobile phones. Researchers opened a web-based community and asked participants to upload diaries with their experience after playing games at home. This task of writing a diary was only assigned to the middle-aged adult group because the older adult group was not familiar with a web-based community.

Data Collection and Analysis

Qualitative Analysis (RQ1 and RQ2)

For qualitative data entries, conversations during coplaying and discussion sessions were recorded and transcribed, including gaming diaries from middle-aged participants. The purpose of the qualitative analysis was to develop a practical mobile design guide for middle-aged and older adults in a holistic manner. The “customer journey map” suggested by service design studies was utilized to include as many game elements as possible, offering contact points between users and gameplay in a coordinated series of processes from the start of the gameplay to the end.

First, we performed inductive thematic analysis on conversation transcripts and gameplay diaries to identify the positive and negative experiences of gameplay. We followed the 6 steps of thematic analysis proposed by Braun and Clarke in this process. Thematic analysis is a useful method for summarizing the key features of a large data set and for gaining a rich understanding of people’s experiences. To familiarize with the data, the first author read all the transcripts and diaries multiple times (step 1). Then, the first author generated initial codes (step 2) and developed these codes into themes of positive and negative experiences (step 3). Three authors reviewed and defined themes through discussion to reach a consensus (steps 4 and 5). All steps were repeated until a final version of the game design guides was acquired (step 6).

Second, we grouped themes of positive and negative experiences under the categories of elements related to gameplay. In order to define these categories, we first identified the basic elements (e.g., audiovisuals, interface) by referring to the fundamental components presented by Ermi and Mäyrä. Then, we added additional elements such as device, platforms, and sales, referring to the contents of a design document presented by Fullerton. Finally, 10 elements were included: (1) cognitive and physical elements that are mainly addressed in existing user experience studies, such as audiovisual, interface, motor skill, and touch interaction; (2) psychological and socioemotional elements related to game content such as game rules, story and character, and social aspects; and (3) consumption contextual elements that are related to the game, such as devices, software installation, advertising, and in-game payments. We included consumption contextual elements in the guide because they also form an integrated user experience with core game elements.

Third, we generated design guides from each theme of experience and recommendation from the participants’ feedback. Three authors and one game design expert reviewed the themes and created proper guides. The final guides were compared with previous works to identify the guides that matched the previous works and the newly discovered guides.

Quantitative Analysis (RQ3)

For quantitative data, we requested survey responses regarding the satisfaction level with each element of the games played at the end of each session. The data were collected because the scores of the commercial games on each element can be a useful indicator for game designers. First, participants rated the satisfaction level of each game’s elements on a 5-point scale for the game they played that day (1=very unsatisfied; 2=unsatisfied; 3=average; 4=satisfied; and 5=very satisfied). Table 4 shows the questionnaire regarding the satisfaction level with each game element. Five face emoticons were used for the 5-point scale to facilitate the answering process for participants.

Second, on the last day of the workshop, participants rated the overall satisfaction level of the game experience for each game on a 5-point scale. This allowed us to examine the satisfaction level when participants first encountered each game and the overall satisfaction after playing the game for a while.
Table 4. Survey questionnaires for measuring the satisfaction level.

<table>
<thead>
<tr>
<th>Game element</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cognitive and physical elements</strong></td>
<td></td>
</tr>
<tr>
<td>Font size</td>
<td>Was the text legible with a reasonable font size?</td>
</tr>
<tr>
<td>Button size</td>
<td>Was the size and location of the button appropriate?</td>
</tr>
<tr>
<td>Sound</td>
<td>Were you satisfied with the sound of the game?</td>
</tr>
<tr>
<td>Information amount</td>
<td>Was there an appropriate amount of on-screen information?</td>
</tr>
<tr>
<td>Button interaction</td>
<td>Did you have any difficulty finding which button to press on each page?</td>
</tr>
<tr>
<td>Speed</td>
<td>Was the game played at a proper speed to understand the content?</td>
</tr>
<tr>
<td>Agility</td>
<td>Was it difficult when you needed a quick reaction? (e.g., selecting moving targets, avoiding obstacles quickly)</td>
</tr>
<tr>
<td><strong>Psychological and socioemotional elements</strong></td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td>Was the goal to achieve in the game clear and appropriate?</td>
</tr>
<tr>
<td>Resource/item</td>
<td>Was the method of using in-game resources and items clear and appropriate?</td>
</tr>
<tr>
<td>Word comprehension</td>
<td>Did you understand the meaning of the words and sentences in the game?</td>
</tr>
<tr>
<td>Mood/character/story</td>
<td>Did you like the atmosphere, character, and story of the game?</td>
</tr>
<tr>
<td><strong>Consumption contextual elements</strong></td>
<td></td>
</tr>
<tr>
<td>Setting to start</td>
<td>How was the setting process to start the game? (e.g., loading the account, setting a nickname)</td>
</tr>
<tr>
<td>Advertising</td>
<td>Were the in-game ads easy to deal with?</td>
</tr>
<tr>
<td>Payment</td>
<td>Did you understand the in-game purchase system?</td>
</tr>
</tbody>
</table>

**Results**

Positive and Negative Experience With Gameplay (RQ1)

We identified 38 themes of positive experiences and 58 themes of negative experiences from dialogues, game diaries, and observations. The most frequently mentioned negative experience was difficulty in understanding the game rules. The second was frustration caused by repeated failures in action games because of lack of agility. The third was difficulty in distinguishing between important objects of similar color or design. Interestingly, the pleasure of playing together was found to be the most positive experience, followed by cognitive training. The third was sensational pleasure derived from special audiovisual effects such as all objects bursting at once. Based on the identified themes of positive and negative experiences, we proposed 45 mobile game design guides for the middle-aged and older adult population. For detailed lists of themes and guides, see the supplementary material (Multimedia Appendix 1).

Mobile Game Design Guides for the Middle-Aged and Older Adult Population (RQ2)

Design Guides Related to Cognitive and Physical Elements

Table 5 shows the design guidelines related to cognitive and physical elements. We presented not only the proposed guides but also previous works that are consistent with our findings.
Several previous studies have reported design recommendations that consider age-related changes such as font size, interface, and motor skills in user interface design, including digital games [20,22-26,36,62]. We found similar experiences, especially in audiovisuals and interfaces. Negative experiences related to declining vision were most frequently identified. In addition, participants had negative experiences in complex interface designs that were cognitively burdensome.

Touch interaction in games is unique for older adult participants who lack gameplay experience and who are not familiar with sliding or swapping interactions. We developed design guides 11-14 based on the failure cases of touch interaction. Most failure cases were observed in older adult participants. We found that participants slid objects in the wrong direction or forgot to pull a finger away from the screen after the action. In addition, some participants mistakenly performed a tap action when a slide was required. Several participants failed to double-click because they tapped once or too slowly. Confusion among participants was aggravated when complex touch-interaction methods were required. The older adult group played “Lonely One: Hole-in-one,” in which a parabola appears when the player touches anywhere on the screen. The player should adjust the position of the parabola and release it, causing the object to move along the parabola. This interaction method is similar to the popular game “Angry Birds.” Participants often failed to draw a correct parabola because they touched the wrong starting point (too close to the edge of the screen). Moreover, they tried to draw a line with their finger along the parabolic dotted line. In addition, we found that participants felt uncomfortable when the speed of the moving character was too fast or too slow. We developed 4 guides regarding motor skills (design guides 15-18).

### Design Guides Related to Psychological and Socioemotional Elements

Table 6 shows the design guidelines related to psychological and socioemotional elements. Similar to that reported in previous research [17,25,36,43], our participants easily adapted to a game that had clear goals and simple rules, but they became frustrated with a game that was difficult and insufficiently explained. They said they forgot the rules quickly over time, although they had learned how to play it. Therefore, we developed design guide 19 that offers sufficient explanation of the game rules [25] and design guide 20 that provides options for selecting the difficulty levels [25,36,43]. Furthermore, new design guides were developed from participants’ feedback, such as providing hints (design guide 21), tips during loading time (design guide 22), and notification messages to prevent resource abuse (design guide 23). In addition, many participants disliked the time limitation in a game; they felt nervous and stressed with the time limits. Therefore, we proposed design guide 25, “eliminate time limits or provide alternatives for level-passing,” which

### Table 5. Mobile game design guides on cognitive and physical elements.

<table>
<thead>
<tr>
<th>Design guide (DG)</th>
<th>Previous works</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Audiovisual</strong></td>
<td></td>
</tr>
<tr>
<td>DG1</td>
<td>Design important object/character as distinguishable from others. [20,22,36,62]</td>
</tr>
<tr>
<td>DG2</td>
<td>Provide voice dubbing when presenting stories or speech bubble. [24]</td>
</tr>
<tr>
<td>DG3</td>
<td>Provide options to choose the size of the font and objects. [20,22,24,25,36]</td>
</tr>
<tr>
<td>DG4</td>
<td>Avoid sounds that are too sharp or repetitive. —</td>
</tr>
<tr>
<td><strong>Interface</strong></td>
<td></td>
</tr>
<tr>
<td>DG5</td>
<td>Present functions step-by-step rather than presenting excessive information in one screen. [20,23]</td>
</tr>
<tr>
<td>DG6</td>
<td>Visually express functions of buttons for illiterate players. [20,23]</td>
</tr>
<tr>
<td>DG7</td>
<td>Avoid multiple button controls at the same time unless they are essential to gameplay. [20,62]</td>
</tr>
<tr>
<td>DG8</td>
<td>Provide user manual that explains the control and function of buttons. [20]</td>
</tr>
<tr>
<td>DG9</td>
<td>Place important buttons in easy to find and touch locations. [26]</td>
</tr>
<tr>
<td>DG10</td>
<td>Provide a mini-map. —</td>
</tr>
<tr>
<td>DG11</td>
<td>Highlight touch area rather than suggesting to touch anywhere. —</td>
</tr>
<tr>
<td>DG12</td>
<td>Provide a tutorial in case of repeated incorrect touch interactions. —</td>
</tr>
<tr>
<td>DG13</td>
<td>Automatically confirm the termination of sliding actions after a specific time period. —</td>
</tr>
<tr>
<td>DG14</td>
<td>Limit the area of operating touchpad on the screen. —</td>
</tr>
<tr>
<td><strong>Motor skills</strong></td>
<td></td>
</tr>
<tr>
<td>DG15</td>
<td>Provide practice session for beginners. —</td>
</tr>
<tr>
<td>DG16</td>
<td>Provide hints for control timing when the player fails repeatedly. —</td>
</tr>
<tr>
<td>DG17</td>
<td>Increase the process speed and difficulty incrementally. [25]</td>
</tr>
<tr>
<td>DG18</td>
<td>Provide speed adjustment function. [25]</td>
</tr>
</tbody>
</table>

*Not available.*
was also proposed in previous studies [20,36]. Some middle-aged participants were satisfied with restrictions on the play opportunities, such as limiting the number of hearts because it prevented them from becoming too addicted to games. We developed a design guide for the time management option, which was also proposed by De Schutter and Vanden Abeele [41].

In terms of story and character, participants expressed dissatisfaction with stories that were too simple or cliché. They were also dissatisfied with stories that lack sympathy or promoted negative emotions such as depression and gloom. Participants also criticized stereotypical expressions regarding the lives of older adults. Instead, participants liked game stories that appealed to and were empathetic to players, stimulated their curiosity, and provided useful knowledge. One participant felt satisfied when another character in the game praised the player. Similar guides and recommendations were reported from previous works [10,36,43]; however, a new guide was proposed regarding a variety of interactive storytelling options such that the player can reflect their own preference (design guide 30). We found many positive effects of gameplay from participants’ feedback and identified those experiences to themes of positive experience under the category of affective aspects: feeling of fun and flow, cognitive skill training, sense of achievement, strategic thinking, concentration, learning something new, killing time, connecting stories to real life experiences and finding meaning, and reminiscing.

Similar to previous studies, we found that many older adult participants perceived gameplay as cognitive training activities [35]. For example, they mentioned “It was good because I feel like [I am] training my brain,” “It is likely to prevent dementia,” and “I feel like I'm getting smarter because I keep using my brain.” Moreover, participants said that the perception of beneficial effects is an important motivation to play. De Carvalho et al [36] also highlighted that clarifying the benefits of the game for older adults is important. We added design guide 31, which informs the affective aspect and beneficial effects of the game such as cognitive training, strategic thinking, learning, connecting real life, and reminiscing. We found that the results were consistent with previous studies on social dimensions [24,41,43]; participants said they had more fun playing with others than when playing alone. They were especially satisfied that they were able to accomplish a difficult mission with supporters on their side. They also felt good when they worked together with an unknown player whom they met in the game to complete the mission. However, some middle-aged participants found it harder to play games with their children because they had different preferences and gameplay skills.

### Table 6. Mobile game design guides on psychological and socioemotional elements.

<table>
<thead>
<tr>
<th>Design guide (DG)</th>
<th>Previous works</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Game rules</strong></td>
<td></td>
</tr>
<tr>
<td>DG19</td>
<td>Provide guidance, tutorials, and practice sessions. [25]</td>
</tr>
<tr>
<td>DG20</td>
<td>Provide options for selecting difficulty levels. [25,36,43]</td>
</tr>
<tr>
<td>DG21</td>
<td>Provide hints when the player fails repeatedly or is taking too much time. —a</td>
</tr>
<tr>
<td>DG22</td>
<td>Provide game rules and tips during loading time (repetitive tutorials). —</td>
</tr>
<tr>
<td>DG23</td>
<td>Provide a notification message if players abuse resources early in the game. —</td>
</tr>
<tr>
<td>DG24</td>
<td>Provide an appropriate challenge rather than a simple or easy rule. [36,42]</td>
</tr>
<tr>
<td>DG25</td>
<td>Eliminate time limits or provide alternatives for level-passing. [20,36]</td>
</tr>
<tr>
<td>DG26</td>
<td>Provide time management options. [41]</td>
</tr>
<tr>
<td><strong>Story and character</strong></td>
<td></td>
</tr>
<tr>
<td>DG27</td>
<td>Provide familiar languages and concepts to the player (eg, based on culture and age). [20,26]</td>
</tr>
<tr>
<td>DG28</td>
<td>Provide players with complimentary messages or motivational feedback. [10,36,43]</td>
</tr>
<tr>
<td>DG29</td>
<td>Do not indicate life of older adults in static, passive, negative, and depressed tones. [63]</td>
</tr>
<tr>
<td>DG30</td>
<td>Provide options for players to choose stories and reflect diversity. —</td>
</tr>
<tr>
<td><strong>Affective aspect and perceived benefit</strong></td>
<td></td>
</tr>
<tr>
<td>DG31</td>
<td>Inform players of the affective aspect and beneficial effects of the game (eg, cognitive training, strategic thinking, learning, connecting real life, reminiscing) [36]</td>
</tr>
<tr>
<td><strong>Social aspect</strong></td>
<td></td>
</tr>
<tr>
<td>DG32</td>
<td>Consider using multiplayer mode or coplaying context in single play mode. [24,41,43]</td>
</tr>
<tr>
<td>DG33</td>
<td>Remove chat features in competitive games or only allow consensual chat between players. —</td>
</tr>
<tr>
<td>DG34</td>
<td>Restrict the use of abusive language. —</td>
</tr>
</tbody>
</table>

[a]Not available.
One middle-aged participant was rather satisfied with the lack of chat function when playing “Brawl Stars” because she never heard swear words or slang from other players. Alternatively, it was less burdensome if the chat function was set to be available after establishing some acquaintances. However, participants were uncomfortable when the method for connecting to social media or inviting friends was complicated. Some participants were concerned about other people; they were worried about bothering others while turning the sound on or exhibiting excessive action during gameplay. One participant said that she did not want to connect to social media and show others that she played games because there were many formal relationships on social media.

**Design Guides Related to Consumption Contextual Elements**

Table 7 shows the design guidelines related to consumption contextual elements, such as devices, software installation, and advertising/payment. Most guides under this category are newly written. We found that older adults preferred using tablet personal computers rather than mobile phones because of their deteriorating eyesight resulting from aging. However, using tablet personal computers was not comfortable when participants unintentionally touched the screen. Furthermore, because of the apparent lack of moisture on their fingers, touch recognition did not work well for some of the participants. We provided additional equipment such as touch pens and controllers; touch pens worked well with games where small objects were to be touched. Similarly, middle-aged adults preferred using a specially developed controller while playing “Brawl Stars.” Therefore, encouraging the use of appropriate devices and additional equipment for middle-aged and older adults may be useful. Installing game software on devices is a challenge for some older adult participants who lack experience in using smartphones. They had difficulty typing and searching for apps. However, they became accustomed to it through repeated practice. Participants said they felt confused with different games having similar titles. Many older adult participants could not remember their IDs and password. Without help, it was difficult for them to register for or log into a game. This issue has been reflected in design guide 38, but special care is needed to prevent misuse of personal information. In contrast, middle-aged adults did not have much trouble with their installation. However, waiting for large files to download was boring for some participants and they did not want to pay for data usage to download games.

Participants felt uncomfortable and bored when there were too many ads or when the ads were too long. In addition, they felt uncomfortable when they are suddenly required to watch an ad while playing because it interrupts their game flow. They were upset that advertisements with inappropriate content such as adult content suddenly appear sometimes without any notification. Participants sometimes became confused whether the pop-up interaction was an advertisement or the game they were playing. They were also confused because they did not know how to turn the ads off, especially when the clickable “close” button feature was too small or when there was a countdown before the appearance of the close button. Participants hoped to be provided with items, hints, and other benefits of gameplay when watching advertisements. Some older adult participants were very generous regarding advertisements. They said that it was okay because they could take a short break and were provided new information during the advertisement.

Regarding payment, older adult participants had no intention of purchasing games or items. They did not connect their credit card to the app store because they were afraid of being mischarged. However, some middle-aged adults paid to buy items to gain an advantage in the game. Both groups were offended when phrases inducing such charges appeared at a difficult level.

<table>
<thead>
<tr>
<th>Design guide (DG)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Devices</strong></td>
<td></td>
</tr>
<tr>
<td>DG35</td>
<td>Able to play both in a tablet personal computer and mobile phone.</td>
</tr>
<tr>
<td>DG36</td>
<td>Provide supportive equipment (eg, touch pen, controller).</td>
</tr>
<tr>
<td><strong>Installation and setting to start</strong></td>
<td></td>
</tr>
<tr>
<td>DG37</td>
<td>Inform expected install time and file sizes.</td>
</tr>
<tr>
<td>DG38</td>
<td>Load account information automatically with privacy precautions.</td>
</tr>
<tr>
<td>DG39</td>
<td>Use easy and unique game titles, which do not overlap with other games.</td>
</tr>
<tr>
<td><strong>Advertisement and payment</strong></td>
<td></td>
</tr>
<tr>
<td>DG40</td>
<td>Provide items and hints after viewing ads.</td>
</tr>
<tr>
<td>DG41</td>
<td>Avoid excessive or long ads, which interrupt gaming.</td>
</tr>
<tr>
<td>DG42</td>
<td>Make it easy to turn off the ads.</td>
</tr>
<tr>
<td>DG43</td>
<td>Present suitable ads for ages and preference (avoid inappropriate content).</td>
</tr>
<tr>
<td>DG44</td>
<td>Let the player choose the timing for advertisements (avoid sudden ads that interrupt the game flow).</td>
</tr>
<tr>
<td>DG45</td>
<td>Noninteractive ads are preferred over interactive ads.</td>
</tr>
</tbody>
</table>
Satisfaction Level in Each Element of the Games (RQ3)

Figures 2-4 show participants’ satisfaction level for each game’s elements and overall satisfaction on the 5-point scale. The goal of this descriptive statistics is to provide game designers with a visual profile of how players are satisfied with game elements in the game case. The satisfaction level for each game’s elements was measured in each session; therefore, they were treated as first impressions after the first 30 minutes of gameplay. The overall satisfaction level in each game was measured on the last day of the workshops. This score is a satisfaction evaluation by comparing it to other games after several days of gameplay. Overall, we can observe from the figures that the satisfaction level with the individual elements performed on each session tended to be higher than the overall satisfaction evaluated on the last day of the workshop. For additional information on Figures 2-4 such as the mean and standard deviation (SD) of the satisfaction levels in each game, see the supplementary material (Multimedia Appendix 2).

Regarding games played by both groups (Figure 2), the mean scores of “Fruit Ninja” in all game elements were over 4.0, except for advertising/payment, but the overall satisfaction was only 3.46 (SD 1.35). It is assumed that even though this game was intuitive and easy to use, there were wide differences in the overall preference between the participants. The scores of “font size” were a bit lower on “Homescapes” and “Long Journey of Life” than those of other elements; we found that many participants mentioned that the text is too small in those games.

In addition, the button interaction of “Brawl Stars” was also low (mean 3.64 [SD 1.08]), which seems to have been difficult for participants to control buttons simultaneously using both hands.

Regarding games played by the middle-aged group only (Figure 3), action games such as “Brawl Stars” and “Sally’s law” were found to be less satisfactory with agility than other elements, and the overall satisfaction was low. The 2 games seem to provide participants with too much difficulty in terms of agility.

Figure 2. Satisfaction levels in games played by both groups.
Regarding games played by the older adult group only (Figure 4), the mean scores of “Word Tower-World Trip” were estimated to be over 4.0 in almost all elements, with a high overall satisfaction level (mean 4.15 [SD 1.04]). Scores of “objective” and “word comprehension” in “Go-stop Plus” were high because it was a digital version of the traditional Korean card game popular with older adults. However, font size was less satisfactory than other elements in this game. Regarding “button interaction,” “Lonely One: Hole-in-one” scored only 3.65 (SD 1.00), apparently because adjusting the position of the parabola to determine the direction of the ball’s flight was unfamiliar to older adults.

**Figure 4.** Satisfaction levels in games played by the older adult group.

**Timeline of the Study**
This project was funded from April 2019 to December 2021 and approved by the institutional review board on June 7, 2019. The data were collected at the workshops involving 40 middle-aged and older adults and 11 young partners from July 1, 2019 to August 28, 2019.

**Discussion**

**Overview of This Study**
The purpose of this study was to derive mobile game design guidelines for the middle-aged and older adult population by analyzing user experience through a qualitative thematic analysis. We proposed 45 guides under the framework of 10 game elements. In addition, we reported descriptive statistics showing the satisfaction profiles for 9 game cases. Based on these results, we had the following discussion.
Embrace the Middle-Aged and Older Population: Reaffirmed Guides and Newly Discovered Guides

Previous studies reported that aging issues such as decreased eyesight, memory, and motor skills could lead to difficulties in playing digital games targeted at the younger generation [15,16,18]. Game design guides for older adults should focus on age-related changes and game elements [22-25]. This study reaffirmed these previous issues and noted that these guidelines have not been applied to many commercial mobile games. We rediscovered repeatedly reported issues such as the size of the text and objects, cognitive burden at the interface, and agility problems. These confirmed guidelines should be essential considerations for game designers who want to create games that cater to the middle-aged and older adult population. In previous studies, it was rare to observe all contact points from the beginning to the end of the mobile gaming experience. By including the context of game consumption, this study was able to introduce new guidelines. These are the parts related to the unique touch interaction used in the game and the parts related to the use of the app store and advertising/payment features embedded in the gaming experience.

Prior Experience of Computer and Digital Games

The use of new technologies is more likely to be a response to historical changes in the older generation than age-related declines [64]. We also found that the prior experience in using digital devices and games affects the participants’ overall gameplay. This is because many digital games require basic digital skills such as installation, typing, double-clicking, and cancellation. While middle-aged participants who are already experienced in the use of computers and smartphones had no problems with installation, typing, and various touch-based interactions, older adult participants needed more help to familiarize themselves with basic operations. In addition, many games use the design elements of earlier successful games. For example, gamers are familiar with a heart-shaped icon that implies remaining opportunities. Moreover, digital games of the same genre often use similar interaction methods. Therefore, compared to the younger generation who are unconsciously trained on these norms through various games since childhood, older adults, who lack gameplay experience, need time to adapt to a new game. Because of these factors, participants recognized gameplay as a learning activity rather than a leisure activity. Charlier et al [65] stressed that older adults’ experiences may include more traditional learning and less game-based learning. Our participants wanted to read specific manuals or learn from others before they started playing. In addition, participants mentioned that they had to recognize the benefits of a game and how it helped them start the gameplay. Therefore, when encouraging older adults to play games, it will be necessary to persuade them to show them how these games are beneficial to them [34,36,37]. In addition, it is recommended to provide game literacy education programs, which introduce the benefits of games, recommend proper games for them, and explain how to play games.

Game Aesthetics and Socioemotional Aspects for the Middle-Aged and Older Adult Population

According to the mechanics, dynamics, and aesthetics framework proposed by Hunicke et al [66], aesthetics refers to the emotions that the player experiences while playing the game. The game designer wants to arouse certain emotional responses in the player, such as sensation, fantasy, narrative, challenge, fellowship, discovery, expression, and submission. De Schutter [67] extended the list to include older adults’ gaming experience and presented 6 items as “Geronto-Aesthetics,” such as cultivation, compensation, connectedness, contribution, nostalgia, and contemporaneity. Through our empirical research, we discovered themes consistent with those in previous studies: challenge (sense of achievement, strategic thinking, and concentration), sensation (feeling of fun and flow), discovery (learning something new), submission (killing time), cultivation (connecting stories to real life experiences and finding meaning), and nostalgia (reminiscing). Moreover, we identified one more item, that is, cognitive skill training. Gameplay is a meaningful activity for older adults because they are interested in cognitive training and in mitigating dementia [35].

Regarding the social aspect of the gaming experience, participants enjoyed playing games together [38,39] and they positively evaluated the interactions with the younger generation. In this study, playing together does not necessarily mean solely playing multiplayer games. Various social interactions could also occur during games that offer only single-player options, for example, turn-taking, score competition, helping with difficult parts, and vicarious play. Young adult partners acted as supporters and coplayers during the workshop; without this help, it would have been even more difficult for the older population to use the game alone. In addition, participants preferred cultural content that they were familiar with, and many women were reluctant to engage with violent content [16].

Limitations and Future Works

There are several limitations associated with this study and a number of issues that remain unexplored. First, a limited number of games were played because of the short workshop duration. Users’ personal preference and styles are important factors, but we did not reflect them when we chose the games. Depending on the diverse interests of middle-aged and older adults, we need to discover and expose them to more games suiting their preferences.

Second, extra caution is required to generalize the results because we could not recruit a more diverse participant pool. All the participants were Koreans, and the results could vary depending on participants from different cultural backgrounds and technology dissemination. In addition, we could not recruit participants who are prescribed or recommended gaming but who have no affinity to games. Moreover, as more female participants were recruited, the study does not include plentiful experiences of male participants. However, since mobile games are especially popular with middle-aged and older women [3], their experiences might be meaningful for mobile game designers.
Third, special attention is required when interpreting the results because the presence of young adults in the workshop setting could impact the gaming experience of participants. Our participants were able to obtain immediate help during the workshop from young partners; however, in many cases, playing alone would likely cause more difficulties.

Fourth, the scope of the quantitative analysis reports descriptive statistics at the exploration stage. The purpose of the quantitative analysis was to provide a useful indicator to game designers by showing the visual profiles of each case. Therefore, these tentative results require further refinement in strictly controlled experiments.

Lastly, with regard to the prior experience with computers and digital games, we found that there were differences between middle-aged adults and older adults in terms of gaming experience, but further research is needed to clarify these differences. In addition, when the digital native generation in their 20s and 30s is older, this guide is likely to have different criteria. Technologies are gradually evolving to be available intuitively without special learning. Therefore, this guide will require continuous updates through user studies from different cohorts.

**Conclusion**

This study includes considerations when creating games for the middle-aged and older population. Game design guides were produced based on the feedback of middle-aged and older adults during the game workshops, where they played mobile games of various genres. The implications of this study are suggesting a design guideline focusing on 10 categories of game elements. Consequently, game designers can holistically understand the game experience of older adults and easily find the relevant information. In addition, our empirical research was able to reaffirm the proposals from previous works that sought to improve the usability of a user interface. Furthermore, we also provided new guides for game design, such as touch interaction, game rules, stories, and advertising/payments. We found that most elements that participants were uncomfortable with during gameplay could be applied to all generations, regardless of age. The young generation also experiences difficulties with using touchscreen technologies, but they are better at adopting technological changes [68]. Thus, improving older adults’ gaming experience may improve the experience for other generation groups as well. Rather than having special game design rules for the older population, we found that a universal design that can be easily accessed by gaming novices irrespective of their generation, is more important. In addition, design guides targeting specific capabilities and limitations are not effective because the older population is diverse in its ranges and combinations of limitations [69]. We hope this guide will be useful for various activities related to gameplay for the middle-aged and older adult population, such as for developing games targeting this population, modifying existing games while considering accessibility, and developing game-related educational programs for this population.

**Acknowledgments**

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**Conflicts of Interest**

None declared.

Multimedia Appendix 1

Mobile game design guides for the middle-aged and older adult population.

[PDF File (Adobe PDF File), 93 KB - games_v9i2e24449_app1.pdf ]

Multimedia Appendix 2

Descriptive statistics of participants’ satisfaction levels in each game case.

[PDF File (Adobe PDF File), 215 KB - games_v9i2e24449_app2.pdf ]

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Abbreviations

RQ: research question
A Virtual Reality–Based App to Educate Health Care Professionals and Medical Students About Inflammatory Arthritis: Feasibility Study

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Abstract

Background: Inflammatory arthritides (IA) such as rheumatoid arthritis or psoriatic arthritis are disorders that can be difficult to comprehend for health professionals and students in terms of the heterogeneity of clinical symptoms and pathologies. New didactic approaches using innovative technologies such as virtual reality (VR) apps could be helpful to demonstrate disease manifestations as well as joint pathologies in a more comprehensive manner. However, the potential of using a VR education concept in IA has not yet been evaluated.

Objective: We evaluated the feasibility of a VR app to educate health care professionals and medical students about IA.

Methods: We developed a VR app using data from IA patients as well as 2D and 3D-visualized pathological joints from X-ray and computed tomography–generated images. This VR app (Rheumality) allows the user to interact with representative arthritic joint and bone pathologies of patients with IA. In a consensus meeting, an online questionnaire was designed to collect basic demographic data (age, sex); profession of the participants; and their feedback on the general impression, knowledge gain, and potential areas of application of the VR app. The VR app was subsequently tested and evaluated by health care professionals (physicians, researchers, and other professionals) and medical students at predefined events (two annual rheumatology conferences and academic teaching seminars at two sites in Germany). To explore associations between categorical variables, the $\chi^2$ or Fisher test was used as appropriate. Two-sided $P$ values $\leq 0.05$ were regarded as significant.

Results: A total of 125 individuals participated in this study. Among them, 56% of the participants identified as female, 43% identified as male, and 1% identified as nonbinary; 59% of the participants were 18-30 years of age, 18% were 31-40 years old, 10% were 41-50 years old, 8% were 51-60 years old, and 5% were 61-70 years old. The participants (N=125) rated the VR app as excellent, with a mean rating of 9.0 (SD 1.2) out of 10, and many participants would recommend use of the app, with a mean
recommendation score of 3.2 (SD 1.1) out of 4. A large majority (120/125, 96.0%) stated that the presentation of pathological bone formation improves understanding of the disease. We did not find any association between participant characteristics and evaluation of the VR experience or recommendation scores.

**Conclusions:** The data show that IA-targeting innovative teaching approaches based on VR technology are feasible.

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**KEYWORDS** feasibility; virtual reality; inflammatory arthritis; psoriatic arthritis; rheumatoid arthritis

**Introduction**

Inflammatory arthropathies (IA) such as rheumatoid arthritis (RA) or psoriatic arthritis (PsA) are complex diseases affecting millions of people worldwide, causing functional impairment and a reduced quality of life [1,2]. Owing to the chronic inflammation, in addition to joint symptoms, some patients with RA or PsA can also experience localized or generalized bone disease. Local bone changes (erosions, bone proliferation) result in functional impairment, while systemic bone loss and worsening biomechanical properties increase the risk of developing osteoporosis and pathologic fractures [3-5].

Imaging is one of the key tools for an early diagnosis of IA, as well as for monitoring and understanding the bone pathology. Various imaging techniques can help to detect pathologic structural changes, and to assess bone density and quality. X-ray, as a 2D imaging instrument, is well-established in routine clinical practice, and is frequently used for assessing catabolic (erosion) and anabolic (bone proliferation) changes or joint space narrowing. Using high-resolution peripheral quantitative computed tomography (HR-pQCT) can further help to characterize joint disease in IA with an in-depth 3D analysis of erosive and osteoproliferative changes, precise quantification of trabecular and cortical bone densities, and assessment of biomechanical properties [6-9].

Recent data show that there is still room for improvement in the understanding and recognition of pathologies, interpretation of image findings, as well as in the appropriate usage of proper imaging techniques [10-12]. Accordingly, there seems to be some concern about musculoskeletal imaging, particularly among health professionals in training [10-12]. Moreover, physicians, medical students, and health professionals explicitly state a need for more in-depth training in imaging and its interpretation regarding musculoskeletal disorders [10,13-15].

To improve the teaching of musculoskeletal imaging, conventional teaching methods such as textbooks, online services, and simulators already exist, which impart knowledge through a systematic and standardized approach. One of these teaching tools is the imaging course of the European League Against Rheumatism (EULAR). Virtual reality (VR) technology can be used to complement these established traditional methods. VR refers to a realistic and immersive simulation of a 3D environment created with interactive software and hardware that is experienced and controlled by movements of the body. In contrast to traditional teaching tools, VR technology has the advantage of visualizing images of various imaging tools such as computed tomography in three spatial axes. The VR technique allows users to see and interact with 3D objects. This so-called “immersive” experience enables the consumer to touch, rearrange, scale, and walk through the objects (to see the inside of the image objects). Previously, VR apps were investigated in several patients with different diseases [16]. In the field of rheumatology, two studies have focused on different patient groups and evaluated how VR apps can lead to improved health care. Venuturupalli et al [17] showed that VR apps could be a viable solution for the treatment of pain and anxiety in rheumatic patients. In addition, Botella et al [18] demonstrated that usage of VR can have a long-term benefit with significantly reduced pain and depression in patients with fibromyalgia. However, all of these studies were patient-focused applications of VR.

Recently, University Hospital Erlangen and the Bamberg Hospital (a teaching hospital) started developing a VR app (Rheumality) that contains 2D and 3D data of the pathologic joints from real patients with RA and PsA at different stages of the disease [19]. These imaging data were combined with the corresponding medical history and clinical data. This app uses immersive sensation that could improve the understanding of chronic inflammatory changes in the joints and bones of patients with IA. Users can touch, scale, or even immerse themselves in the typical bone and joint pathologies of RA or PsA, such as erosions, new bone formations, or bone loss. The advanced visualization and interactivity of 3D bone images paired with the corresponding medical history offer potential to improve training and education in rheumatology. Ideally, the virtual world will contribute to enhancing end-user knowledge and help to acquire confidence in the management of IA.

However, the feasibility of a VR app in teaching about IA has not yet been evaluated, and therefore its potential benefits have not yet been assessed. In this study, we evaluated the feasibility of the Rheumality VR app that was developed specifically to educate health care professionals and medical students about IA. We investigated the general impression, knowledge gain, and possible applications using data from physicians, researchers, and other health care professionals working in the field of rheumatology as well as medical students.

**Methods**

**Development of a VR App for Educational Purposes in IA**

In 2016, University Hospital Erlangen (Erlangen, Germany) and Bamberg Hospital (Bamberg, Germany) started to develop an educational VR app (called Rheumality) based on real anonymized patient cases with corresponding clinical and imaging data to provide health care professionals and medical
students with a better understanding of IA [19]. The imaging data focused particularly on peripheral X-rays and HR-pQCT images of the arthritic joints and bone structures. The version (2.1) of Rheumality used for this study included three case examples (two RA cases and one PsA case), and was developed for the above-mentioned targeted population (Figure 1). All patients agreed to the use of their anonymized data and signed an informed consent form, which was approved by the Ethics Committee of Friedrich-Alexander-University (324_16B).

For each case, brief clinical information about disease history (e.g., initial diagnosis, symptoms, treatment, response to treatment, disease perception, patient reported outcomes) is given to the user (Multimedia Appendix 1). The user has to participate actively, and has to indicate the typical arthritic joint and bone pathologies on the basis of 2D X-ray images of the hands (Figure 1A) and 3D HR-pQCT images of the finger joints (Figure 1C). Subsequently, the participant is asked to estimate how much the patient is restricted in different areas of life, taking into account the pathologies depicted in the images (questions based on the Modified Stanford Health Assessment Questionnaire [20]) (Figure 1B). Each case (tutorial) is designed to last 10 minutes.

Figure 1. Learning tasks in the VR application for teaching of IA. Depiction of 2D hand X-ray of a patient with arthritis on which the user has interactively identified joint pathologies (green circles) (A). In another task, the user is asked to assess the disease burden of the same patient after evaluating the X-ray images (B), 3D CT image of the same pathologies of the X-ray image, the user can rotate and immerse with these images and is asked to define specific pathologies such as erosions (red circle) (C). (A, C) show images of a patient with long-standing (inadequately treated) RA, (D) CT images of a patient with early RA.

Technical Equipment for the VR Experience
A notebook Acer Predator Helios 500 (Intel i7-8750H, NVIDIA GeForce GTX 1070; acquisition cost: US $2417) and HTC Vive VR headset (2x OLED 1080 x 1200, 90 Hz, FOV 110°, 2x Lighthouse Tracking, Motion Controller; acquisition cost: US $628) were used in this study. The setup time was 5 minutes to clear the required space in a room (safety measure), connect all devices, switch them on, and set up and run the VR app. Pictures of the equipment are provided in Figure 2.

Figure 2. Applied technical virtual reality (VR) equipment. For the VR experience, a Notebook (Acer Predator Helios 500) (A), VR set (VR Headset HTC VIVE) (B), motion controller (C), and Lighthouse Tracking (D) are necessary.

Questionnaire Development
To evaluate possible applications and benefits for improved disease understanding from using the VR app, a questionnaire was designed in a consensus meeting (web-based, involving authors PK, AK, DS, AH, PS, AF) after initial individual research of the current literature and a definition of the issues to be addressed [21,22]. Results of the respective consultations were then assessed by the group: each single item and wording was presented to all experts, followed by a vote about the inclusion. For a question to be accepted for the final questionnaire, a majority vote of 75% was required. This method was chosen in analogy to the EULAR recommendation task force [23].

Thirteen questions were included in the final questionnaire covering how the VR app and the VR itself were perceived. All questions of the questionnaire are depicted in Multimedia Appendix 2. In addition, basic demographic data (gender, age category, and profession) were collected.

Evaluation of the VR App as a Teaching Tool
The VR app (Rheumality version 2.1) was provided to a professional audience at predefined events according to a standardized scheme and subsequently evaluated using the developed questionnaire. The professional community consisted of health professionals working in the field of rheumatology (physicians, researchers, and other health professionals) and medical students. Three different methods for exploitation and evaluation were selected to reach the broadest possible target...
population: (i) the annual German Society of Rheumatology conference 2019 in Dresden, Germany; (ii) the German Imaging Course in Rheumatology (Deutscher Bildgebungskurs) 2019 in Duesseldorf, Germany; and (iii) academic teaching seminars (from October 2019 to March 2020) for medical students at two different German universities (Campus Kerckhoff of Justus-Liebig-Universität Gießen and Friedrich-Alexander-University Erlangen). During events (i) and (ii), the possibility of participation was advertised to the public through flyers, posters, and a trade fair booth. Regarding (iii), the students were directly approached in corresponding teaching seminars about their interest in participating. Inclusion criteria were aged above 18 years and belonging to one of the following professional backgrounds: medical student, resident, specialist (hospitalist), specialist (outpatient practitioner), researcher, other health care professional (eg, nurse, study nurse). Pregnant participants as well as participants suffering from nausea, vomiting, dementia, motion sickness, stroke, seizure, and epilepsy were not allowed to participate. To qualify for the evaluation, all individuals had to complete the full VR tutorial (10 minutes). Directly after the VR experience, the participants were asked to answer the questionnaire once providing informed consent. Prior to each VR session, the participants were informed by a trained member of the research team (LS, TM, FS, PK, DS, AK) about the background of the app (presentation of real patient cases in combination with the respective images of the associated pathologic joints), basic control mechanism, and safety measures (eg, what to do when feeling uncomfortable). Each VR session was accompanied by a qualified staff member (LS, TM, FS, PK, DS, AK), who also evaluated subsequent side effects. The app was evaluated by participants directly after the VR session using the developed questionnaire based on a web-based survey (SurveyMonkey Inc).

Statistical Analysis
Nominal and ordinal variables are described by counts and percentages, and interval scaled variables are described by mean and SD. To explore associations between categorical variables, the $\chi^2$ or Fisher test was used as appropriate. Two-sided $P$ values $\leq 0.05$ were regarded as statistically significant. Data were analyzed using SPSS for Windows (SPSS 26, IBM Corporation).

Results

Study Participants
A total of 133 individuals were tested for eligibility, 8 of whom had to be excluded (history of nausea, epilepsy, and motion sickness; presence of pregnancy), resulting in a final dataset from 125 individuals included for analysis. Among these 125 participants, 50 were physicians, including 27 specialists in rheumatology (16 hospitalists, 11 outpatient practitioners), 23 residents, 5 researchers, and 4 other health care professionals (Table 1). The remaining participants were medical students (n=66). Seventy of the 125 participants (56.0%) identified as female, 54 (43.2%) identified as male, and 1 (0.8%) identified as nonbinary. Among the 125 participants, 74 (59.2%) were 18-30 years of age, 22 (17.6%) were 31-40 years old, 13 (10.4%) were 41-50 years old, 10 (8.0%) were 51-60 years old, and 6 (4.8%) were 61-70 years old. Overall, 16% (20/125) of the participants already had experience with VR technology.

Table 1. Professional background of participants (N=125).

<table>
<thead>
<tr>
<th>Profession</th>
<th>Participants, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical student</td>
<td>66 (52.8)</td>
</tr>
<tr>
<td>Resident</td>
<td>23 (18.4)</td>
</tr>
<tr>
<td>Specialist (hospitalists)</td>
<td>16 (12.8)</td>
</tr>
<tr>
<td>Specialist (outpatient practitioner)</td>
<td>11 (8.8)</td>
</tr>
<tr>
<td>Researcher</td>
<td>5 (4.0)</td>
</tr>
<tr>
<td>Health care professional</td>
<td>4 (3.2)</td>
</tr>
</tbody>
</table>

General Feedback on the Imaging VR App

The participants generally rated the app as excellent. The overall rating (best rating: 10, worst rating: 0) of the VR app was excellent (mean 9.0, SD 1.2), and participants could imagine recommending the app to others (mean 3.2, SD 1.1), based on a scale from 0 (not at all) to 4 (definitely) (Figure 3). Using the $\chi^2$ test, neither age nor profession was significantly associated with a given evaluation of the VR app ($\chi^2=21.7, P=.15$ and $\chi^2=12.7, P=.89$, respectively) or a special recommendations to friends and family ($\chi^2=14.6, P=.89$ and $\chi^2=13.8, P=.54$, respectively). The majority (102/125, 81.6%) of participants indicated that they would use the app themselves if it was available for download in an app store. When asked to evaluate the intuitiveness of the VR app, 109 of the 125 participants (87.2%) considered the control to be intuitive, whereas only 7 out of 125 (5.6%) found the VR app to be confusing. All 7 participants rating the VR to be confusing were under 41 years of age (6 were 18-30 years old and 1 was 31-40 years old). However, there was no statistically significant association with age ($\chi^2=2.647, P=.62$). The vast majority (109/125, 87.2%) also rated the amount of time they spent on the virtual patient case to be optimal.
Figure 3. Feedback on the virtual reality (VR) app Rheumality. Overall rating (range 0-10) on the VR app divided into four different professional subgroups (A) and age subgroups (C). Recommendations of the VR app in the four different professional subgroups (B) and age subgroups (D) on a scale of 0 (not at all) to 4 (definitely). In the boxplots, crossbars represent medians, whiskers represent the 5th-95th percentiles (points below the whiskers are drawn as individual points); the box always extends from the 25th to 75th percentiles (hinges of the plot). HC: health care professionals.

Knowledge Dissemination by the VR App
When asked whether the presentation of the pathologic bone formation improved disease understanding, 120 of the 125 participants (96.0%) answered “yes.” In addition, 124 of the 125 participants (99.2%) stated that the way the disease was represented by the VR app was helpful for gaining a better understanding of the disease. Similarly, 123 of the 125 participants (98.4%) stated an interest in obtaining additional tutorials including new case studies or for other rheumatic diseases.

Feedback on Potential Areas of Application
When asked about further prospects of application, 123 of the 125 participants (98.4%) thought that the developed VR concept based on real medical histories and imaging data could have a positive influence on teaching IA and rheumatology. In accordance with this, 118 of 125 participants (94.4%) were of the opinion that a VR app could be successfully used for teaching about IA and rheumatology. In addition, 51 of the 125 participants (40.8%) saw potential for the app in research, 95 of 125 (76.0%) saw potential for patient education, and 98 of 125 (78.4%) saw potential for training of health professionals.

Harms
One study participant reported nausea and had to stop the VR experience after 6 minutes.
Discussion

Principal Findings
This study demonstrated that a broad professional audience considers an educational VR app (called Rheumality) based on real patient data to have potential for knowledge transfer about IA. The combination of medical history and image data for the same individual convinced the large majority of the participants of the educational benefit of the app. Interestingly, the acceptance of this teaching approach was evident across all age groups and was independent of medical education. Thus, physicians, researchers, and health care professionals working in the field of rheumatology, as well as medical students, would accept and recommend this teaching format as a good knowledge transfer tool. Besides the high acceptance, we also found that the VR app seems to be a safe educational tool, since only one participant had to stop the VR experience due to nausea. With regard to further fields of application, a considerable majority of the participants stated that VR technology has potential for broader areas of implementation. A substantial percentage of the participants could imagine that, in addition to classical teaching and training aspects, patient education could also be a promising field of application.

Traditional teaching approaches based on textbooks or online texts are successful in transmitting knowledge, but the intuitive depiction of 3D imaging reality is limited due to the 2D characteristic of these teaching tools. Therefore, new teaching methods focusing on imaging education can be used as an additional knowledge transfer tool.

Our study shows that many individuals currently consider that the developed VR concept, which utilizes the latest hardware and software possibilities, could have a positive influence on teaching.

There are also various technological developments in rheumatic and musculoskeletal teaching and patient care (such as mobile apps or activity trackers) that take this aspect into account [24,25]. However, to our knowledge, there is no app currently available that transports 3D imaging of real patients in combination with actual patient data on a technological VR basis. Given the recognized importance of IA imaging for diagnosis, monitoring, and prognosis, such a VR app can be valuable in the future to reliably train key players of the health care system for clinical routine practice and training to improve the care of IA patients [14,26,27].

VR technology (goggles and VR-ready computers) is becoming more and more affordable, immersive, and flexible, leading to the expectation that its use in teaching purposes may increase in the coming years [28]. Our study shows that VR apps are already technically at such an advanced level that teaching about IA with VR technology seems feasible.

Limitations
The major limitation of our study is that the effect of learning with this VR app compared with the standard (eg, textbooks) was not evaluated, which is needed to ultimately demonstrate its practical usefulness. For this purpose, further studies will have to be performed in the future. In addition, a specific, advanced VR app was used in this study, which relied on the combination of patient data and real imaging data. Therefore, the results of our survey cannot be transferred to all VR apps. Further, confirmatory studies with larger numbers of participants and more differentiated target audiences, especially patients, are necessary to verify and validate our study results. In addition, the current VR equipment is, compared to traditional teaching methods, relatively expensive for an implementation in clinical practice, with costs of several hundred dollars for a powerful computer and the necessary goggles. Only when acquisition costs continue to decrease, a comprehensive introduction into the clinical health care environment will be possible. It would be useful to perform future studies with additional health care professionals from several countries to transfer our results to the international community.

Comparison With Prior Work
VR apps have been investigated in several patients with different diseases [16]. However, VR apps have rarely been applied in the field of rheumatology to date, and this prior work has thus far been largely patient-focused [17,18]. To our knowledge, there has been no study specifically evaluating the teaching potential of VR in rheumatology or IA until now. The “digital divide” is frequently mentioned when assessing new technologies for a broad audience, meaning that older individuals seem to experience more difficulty in adopting new technologies than younger individuals [29-31]. Interestingly, the tested VR app in this study was rated positively independent of age and profession. Furthermore, only a small minority of participants found the VR experience to be confusing, all of whom were younger than 41 years. A conclusive judgment on this matter would be difficult at this point; however, it could be speculated that this minority of younger users had different expectations in advance due to their previous experience and therefore considered the VR concept to be confusing.

Conclusions
Our study showed that novel teaching approaches based on VR technology are feasible for teaching about IA. The use of VR apps such as Rheumality enables disease-specific knowledge visualization and may add a new educational pillar.

Acknowledgments
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The present work was performed in (partial) fulfillment of the requirements for obtaining the degree "Dr. rer. biol. hum." for DS at Friedrich-Alexander-University Erlangen-Nürnberg. Further support was provided by the Deutsche Rheumastiftung (to DS and PK) and NWT-med of Justus-Liebig-University Gießen (to PK).

## Conflicts of Interest

PK, AK, FH, DS are advisors to Eli Lilly and Company, Germany.

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24. Abbreviations

EULAR: European League Against Rheumatism
HR-pQCT: high-resolution peripheral quantitative computed tomography
IA: inflammatory arthritis
PsA: psoriatic arthritis
RA: rheumatoid arthritis
VR: virtual reality
A Virtual Reality–Based App to Educate Health Care Professionals and Medical Students About Inflammatory Arthritis: Feasibility Study


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User Experience With Dynamic Difficulty Adjustment Methods for an Affective Exergame: Comparative Laboratory-Based Study

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Abstract

Background: In affective exergames, game difficulty is dynamically adjusted to match the user’s physical and psychological state. Such an adjustment is commonly made based on a combination of performance measures (eg, in-game scores) and physiological measurements, which provide insight into the player’s psychological state. However, although many prototypes of affective games have been presented and many studies have shown that physiological measurements allow more accurate classification of the player’s psychological state than performance measures, few studies have examined whether dynamic difficulty adjustment (DDA) based on physiological measurements (which requires additional sensors) results in a better user experience than performance-based DDA or manual difficulty adjustment.

Objective: This study aims to compare five DDA methods in an affective exergame: manual (player-controlled), random, performance-based, personality-performance–based, and physiology-personality-performance–based (all-data).

Methods: A total of 50 participants (N=50) were divided into five groups, corresponding to the five DDA methods. They played an exergame version of Pong for 18 minutes, starting at a medium difficulty; every 2 minutes, two game difficulty parameters (ball speed and paddle size) were adjusted using the participant’s assigned DDA method. The DDA rules for the performance-based, personality-performance–based, and all-data groups were developed based on data from a previous open-loop study. Seven physiological responses were recorded throughout the sessions, and participants self-reported their preferred changes to difficulty every 2 minutes. After playing the game, participants reported their in-game experience using two questionnaires: the Intrinsic Motivation Inventory and the Flow Experience Measure.

Results: Although the all-data method resulted in the most accurate changes to ball speed and paddle size (defined as the percentage match between DDA choice and participants’ preference), no significant differences between DDA methods were found on the Intrinsic Motivation Inventory and Flow Experience Measure. When the data from all four automated DDA methods were pooled together, the accuracy of changes in ball speed was significantly correlated with players’ enjoyment (r=0.38) and pressure (r=0.43).

Conclusions: Although our study is limited by the use of a between-subjects design and may not generalize to other exergame designs, the results do not currently support the inclusion of physiological measurements in affective exergames, as they did not result in an improved user experience. As the accuracy of difficulty changes is correlated with user experience, the results support the development of more effective DDA methods. However, they show that the inclusion of physiological measurements does not guarantee a better user experience even if it yields promising results in offline cross-validation.

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Introduction

Affective Exergames

Exercise games (commonly shortened to exergames) are used to promote enjoyable, intensive exercise in applications such as weight loss and maintenance \[1,2\], healthy aging \[3\], and motor rehabilitation \[4,5\]. In such exergames, tailoring the game difficulty to the player’s abilities and preferences can often improve the user experience, enabling more enjoyable, frequent, and intensive exercise. Such difficulty adjustment can always be performed manually by a player via an interface. However, although manual adjustment is generally accurate, it can cause interruptions in game flow, as users must stop playing the game to adjust difficulty \[6\]. This has led to the development of dynamic difficulty adjustment (DDA) methods, where the game assesses the player’s current state and automatically adjusts the difficulty to bring the player into a more desirable state.

The simplest and most popular DDA methods are based only on performance measures (eg, in-game score), which provide an easily measurable and interpretable indicator of perceived game difficulty. However, although many studies have shown the positive effects of performance-based DDA on user experience \[7\], performance alone does not necessarily provide insight into the player’s psychological state, for example, a frustrated player can get a high score in a game without enjoying it. This has led to the development of affective games, an emerging type of videogame that adapts difficulty based on a combination of the player’s performance and their psychological (cognitive and affective) state. This psychological state can be defined as, for example, the level of anxiety \[8,9\] or via the two-dimensional valence-arousal model \[9,10\] and is commonly inferred from measurements such as an electrocardiogram (ECG), galvanic skin response, and electroencephalography (EEG) using automated classification algorithms. Once the psychological state has been classified, DDA can be performed using rules such as “if performance is high and anxiety is low, increase difficulty.” Thus, incorporating psychological information allows affective games to potentially achieve more effective and personalized DDA than performance-based methods \[11\].

Affective exergames are most prominent in motor rehabilitation, where physiological measurements have been used to estimate psychological states and adjust the difficulty of exercises for both the upper \[5,12-16\] and lower limbs \[17,18\]; they have also been used for general exercise enhancement in several studies \[19,20\]. However, as affective exergames are more complex than simple performance-based DDA, the question arises: does the additional cost and complexity result in a better user experience?

Do Affective Exergames Improve User Experience?

As mentioned, in affective exergames, psychological states are extracted from measurements such as ECG, EEG, and galvanic skin response using signal processing and machine learning techniques. The ground truth for such machine learning is generally the user’s self-reported state or opinion, for example, how anxious they are or how they would like difficulty to be adjusted \[8,11,21\]. The accuracy of DDA is then estimated as the percentage of times that the affective exergame makes the same DDA decision (based on the extracted psychological state) as the user would. This accuracy is never perfect; however, to justify the use of affective games, affective DDA should reach a higher accuracy than performance-based DDA and result in a better user experience than performance-based DDA.

Many studies in both affective exergaming and other fields of affective computing have shown that the addition of physiological measurements allows for a more accurate classification of the player’s psychological state compared with using only performance measurements \[12,17,22-24\]. Furthermore, some studies have shown that affective exergames that perform DDA based on physiological measurements achieve a positive user experience \[5,13-15\]. However, there is little evidence that the user experience achieved with affective exergames is better than that achieved with a performance-based exergame in the same context. To the best of our knowledge, only one study has examined this difference and has found that an affective exergame was more engaging than an equivalent performance-based exergame \[14\]. Even outside affective exergaming, the evidence in favor of affective DDA is limited, with a few studies in entertainment games showing better user experience with affective DDA than performance-based DDA \[8\] and a few studies showing a better user experience with affective DDA than manual (user-guided) DDA \[25,26\], although the user’s decisions are frequently used as the ground truth for training affective DDA.

This lack of evidence showing that affective technologies result in a better user experience than simpler technologies has been acknowledged as a significant issue in affective computing \[27,28\], as calculating the accuracy of psychological state classification or demonstrating a positive user experience with affective DDA may not be enough to show the superiority of affective technologies. For example, our own Wizard of Oz studies in affective games have shown that, although user psychological state classification accuracy is correlated with user experience, the relationship between the two is complex and nonlinear \[29,30\]. Furthermore, studies from other fields of human-machine interaction indicate that offline classification accuracy does not always strongly correlate with user experience or even with real-time (dynamic) classification accuracy \[31,32\]. Thus, lessons learned from offline classification studies cannot be directly transferred to physiology-based DDA. The state of the art in affective exergaming can be summarized as follows: there is evidence that affective exergames result in a positive user experience and that physiology-based psychological state classification is more accurate than performance-based psychological state classification. However, there is very limited evidence that physiology-based DDA (used in affective
exergames) results in a better user experience than performance-based DDA (used in simpler exergames). Additional evidence in this regard is needed to justify the broader adoption of affective exergames.

Goal of the Study

This study aims to evaluate the user experience in an exergame where DDA is performed using one of five methods: manual, random, performance-based (PE), personality-performance–based (PEPE), and physiology-personality-performance–based (all-data). The last three DDA methods were based on classifiers developed for offline psychological state classification in our previous study [33]. In this study, these classifiers were connected to if-then difficulty adjustment rules and used as a basis for DDA. The research questions were as follows:

- Research question 1: do the PEPE and all-data methods result in a better user experience than the PE method? The all-data method can be considered an affective exergame, and the all-data with PE comparison thus represents a direct comparison of affective and performance-based exergames. In our previous study, including personality and physiological measurements increased psychological state classification accuracy compared with using only performance measures [33], but this is not guaranteed to result in a better user experience. The inclusion of personality characteristics was considered separately because tailoring DDA to personality may improve user experience without additional sensors [34];
- Research question 2: do manual and random DDA result in the best and worst user experience, respectively? The user’s preference is commonly used as the ground truth for training DDA algorithms in affective games [8,11,21], so manual DDA should result in a very positive user experience. At the same time, some studies have shown better user experience with physiology-based DDA than with manual DDA [25,26]. Random DDA should result in a poor experience but is included as a baseline;
- Research question 3: is user experience positively correlated with the accuracy of psychological state classification during gameplay? Our previous Wizard of Oz [29,30] studies and others’ studies [28] indicated a correlation between the two, but the nature of this relationship in actual games remains unclear.

Methods

Overview

This paper describes a comparative evaluation of five DDA methods in an affective exergame. Three of these methods were developed based on data recorded in a previous study [33]; thus, we briefly refer to a previous study for better understanding. Both studies were approved by the University of Wyoming Institutional Review Board (protocol no 20190822DN02495).

This section is divided into five subsections. The first subsection presents the exergame used for DDA evaluation, which is identical for both studies. The second subsection describes the different measurement types used as a basis for DDA, which were nearly identical for both studies. The third subsection summarizes the previous study used to train the DDA methods for this study (described in detail in our previous paper [33]). The fourth subsection presents the study protocol. Finally, the fifth subsection presents the outcome variables and data analysis performed to compare the five DDA methods in this study.

Exergame

An exergame version of Pong was reused from our previous research, originally intended for two-player rehabilitation exergaming [35,36], and a single-player version was created for our previous open-loop study [33]. It consists of 2 paddles and a ball on a board. The participant controlled the bottom paddle, while the top paddle was controlled by a computer opponent. If the ball passed either player’s paddle, the other player would score a point, and the ball would start moving again from the middle of the screen. The player moved their paddle left and right by tilting the Bimeo (Kinestica) arm tracking device left and right with their dominant hand. The game was played on a 21-inch screen, with the participant seated approximately 60 cm from the screen. A photograph of this study setup is shown in Figure 1.

The game difficulty can be adjusted using two parameters: ball speed and paddle size. Although the game allows the participant’s and opponent’s paddle sizes to be changed independently, the evaluated DDA methods always changed the 2 paddles simultaneously and identically so that the participant’s paddle was never larger or smaller than that of the computer opponent. The DDA methods used in this study were based on multiple measurements, with the decision-making rules trained based on data recorded in a previous study, as described in the following sections.
Measurements Used as the Basis for DDA

A total of 3 data types were recorded and used as a basis for DDA: physiological responses, performance, and personality characteristics. Physiological responses and performance were recorded continuously during gameplay and thus varied as the difficulty of the game changed. Personality characteristics were collected using questionnaires at the start of the session (after the researcher demonstrated the game but before participants played it) and did not change during gameplay but were expected to influence the participant’s DDA preferences.

The physiological recording process was identical in this study and our previous open-loop study [33] so that the previous data could be directly used to create the DDA methods; parts of the text in this section and Multimedia Appendix 1 are thus rephrased from the previous paper.

Physiological Signals

This study used 2 g.USBamp signal amplifiers and associated sensors (g.tec Medical Engineering GmbH) to measure six physiological signals: 8-channel EEG, 2-channel electrooculogram, ECG, respiration, galvanic skin response, and skin temperature. A seventh physiological signal, point of gaze, was recorded using a GP3 eye tracker (Gazepoint). The sensors used are shown in Figure 1. Detailed information about the measurements is available in Multimedia Appendix 1 but, in brief, they were performed as follows:

- EEG was recorded from 8 locations based on the 10-20 placement system [37]: AF3, AF4, F1, F2, F5, F6, C1, and C2. Feature extraction methods included the lateral power spectrum density [38] and dispersion entropy [39].
- Electrooculogram was recorded from 2 channels reflecting up-down and left-right eye movements. The extracted features were based on its first derivative. In addition, it was used to denoise the EEG signals.
- ECG was recorded using 4 electrodes on the trunk. Extracted features included heart rate and time- and frequency-domain estimates of heart rate variability [40].
- Respiration was recorded using a thermistor-based sensor in front of the nose and mouth. Extracted features included respiration rate and time-domain estimates of respiratory rate variability.
- The skin temperature was recorded using a sensor attached to the little finger of the nondominant hand. Extracted features included the mean temperature and changes in skin temperature across time.
- Galvanic skin response was recorded by attaching a sensor to the index and middle fingers of the nondominant hand. Features were extracted from both the tonic (low frequency) component and the phasic skin conductance responses [41].
- From the eye tracker data, the extracted features included the size of each pupil and the mean gaze velocity.

Physiological features were normalized by dividing each calculated feature value by the feature value obtained during the baseline period.
Performance

The in-game score was used as the only feature to assess participants’ performance. It was defined as the difference between the participant’s score and the computer opponent’s score.

Personality Characteristics

Participants completed four personality questionnaires: the Learning and Performance Goal Orientation measure [42], the Behavioral Inhibition and Activation Scales [43], the Self-Efficacy Scale [44], and the 10-Item Personality Inventory [45]. Questionnaire details are provided in Multimedia Appendix 1.

Summary of the Previous Study

In our previous study [33], 30 healthy university students (mean 24.2, SD 4.4 years; 11 women) participated in a 1-hour session. Physiological signals were first recorded for a 2-minute baseline period, during which participants were instructed to relax, remain motionless, and look at the computer screen. Then, nine game difficulty configurations consisting of combinations of three possible ball speeds (slow, medium, and fast) and three possible paddle sizes (small, medium, and large) were played in random order for 2 minutes each. After each 2-minute interval, a short questionnaire was filled out to assess the perceived difficulty, enjoyment, and two subjective preferences about game difficulty (desired change to ball speed and paddle size). Participants had seven options for perceived difficulty and enjoyment (1 for very low and 7 for very high) and five options for how they would like to change each difficulty parameter, ranging from a decrease by two levels (−2) to an increase by two levels (+2). The order of game difficulty settings was preset randomly for each participant, and the participant’s desired changes to the ball speed and paddle size did not actually affect the game.

The study protocol resulted in a data set with two outputs (desired changes to ball speed and paddle size) and 64 input features calculated during 2-minute gameplay periods: the physiological, personality, and performance features described in Multimedia Appendix 1. Multiple classifiers were developed to categorize the two subjective difficulty adjustment preferences into three classes: increase (+1 and +2), no change (0), and decrease (−1 and −2). Separate classifiers were developed and evaluated for ball speed and paddle size, and separate classifiers were trained for different combinations of the three recorded data types (Multimedia Appendix 1). These classifiers were separated so that a classifier did not have access to the results of another classifier (eg, the ball speed classifier did not have access to the results of paddle size classification and vice versa); however, they were still trained on data from the same participants and gameplay periods, and all had access to current ball speed and current paddle size (as the current game state would be realistically available to any classifier). In all cases, stepwise forward feature selection [46] with an inclusion threshold of \( P = 0.05 \) was first used to select a subset of features. This reduced subset was then used to train four classifier types, of which multiple linear regression resulted in the highest classification accuracy and was thus chosen for this study.

Study Protocol for Comparison of DDA Methods

This study compared five DDA methods using the same study setup and a protocol similar to the open-loop study. A total of 50 healthy university students (mean 25.1, SD 5.9 years; 13 women; 5 left-handed) participated in the study, with 10 assigned to each DDA method. The 5 participant groups went through the same study protocol, which differed only according to the DDA method they were assigned to. Participants were not told which method they were assigned to and had no way of identifying it.

After signing the consent form, filling out the four personality questionnaires, putting on the physiological sensors, and recording the responses for a 2-minute baseline period (same as in the Summary of the Previous Study section), participants started to play the game with a medium difficulty level (speed level 3 in a range of 1-6 and paddle size 2 in a range of 1-4). Every 2 minutes, the game was paused, and participants filled out a short questionnaire to report their perceived difficulty, enjoyment, and the way they would like to change the game parameters (same as in the Summary of the Previous Study section). Participants were allowed to ask for longer breaks in case of dizziness or arm fatigue; however, this only happened after a 2-minute interval among all 50 participants, and dizziness and fatigue were not otherwise tracked. Once the participant was ready to continue, the difficulty level was adjusted by changing the ball speed and paddle size using the DDA method to which the participant was assigned. In all DDA methods, the ball speed and paddle size were adjusted independently of each other. All participants played the game for a total of 18 minutes (nine 2-minute intervals, with difficulty adjustment after each interval) and then completed two outcome questionnaires (see the Outcome Variables and Data Analysis section) to complete the study protocol. The protocol is summarized in Figure 2.

Figure 2. Summary of the study protocol. All participants first completed the personality questionnaires, rested for a 2-minute baseline period, then went through nine 2-minute gameplay intervals (game 1-9), with a short questionnaire after each. Physiological measurements were recorded throughout the baseline and gameplay and separated into 2-minute intervals for analysis. At the end, participants filled out the final outcome questionnaires. PQ: final questionnaire; PQ: personality questionnaire; SQ: short questionnaire.
As mentioned earlier, the participant groups differed according to the DDA method; in total, five methods were used:

1. Manual adjustment: the ball speed and paddle size were adjusted based on the participant’s preferences expressed in the short questionnaire. For each parameter, they had three options: increase by 1 level, no change, and decrease by 1 level.

2. Random adjustment: for both ball speed and paddle size, one of the three options available to the manual method (increase, no change, or decrease by one level) was chosen entirely randomly.

3. PE method: the ball speed and paddle size were adjusted based on three features: the current ball speed, current paddle size, and the in-game score achieved by participants. To perform the adjustment, two multiple linear regression models were trained based on data from a previous study using the three features as the inputs and the adjustment to the ball speed and paddle size as outputs (the exact regression coefficients are presented in Table A1 in Multimedia Appendix 1). The output of each regression model was converted to discrete classes and used to perform difficulty adjustment: increase by 1 level (output of model above 0.5), no change (output between −0.5 and 0.5), and decrease by 1 level (output below −0.5).

4. PEPE method: the ball speed and paddle size were adjusted based on multiple features selected among current game difficulty, in-game scores, and personality characteristics. The adjustment was performed using two regression-based classifiers, as with the PE method, but trained using both performance and personality data. A mix of personality characteristics from all four questionnaires was included in the classifiers, with only self-efficacy and agreeableness included in both classifiers (exact regression coefficients are presented in Tables A2 and A3 in Multimedia Appendix 1).

5. All-data method: the ball speed and paddle size were adjusted based on multiple features selected among current game difficulty, in-game score, personality characteristics (eg, extraversion), and physiological responses (eg, respiration rate). Adjustments were made using two regression-based classifiers developed based on data from a previous study. For both ball speed and paddle size classifiers, the first two selected features were from skin temperature and respiration, and multiple EEG features and multiple personality characteristics were selected (exact regression coefficients are presented in Tables A4 and A5 in Multimedia Appendix 1).

Among the five DDA methods, only the manual method took the participants’ preferences regarding game difficulty into account. Furthermore, limits were put in to ensure that the ball speed and paddle size did not exceed the preset limits. Specifically, if a DDA method’s decision would have caused a parameter to exceed a minimum or maximum value (1-6 for ball speed; 1-4 for paddle size), it instead stayed at that extreme value.

**Outcome Variables and Data Analysis**

The primary outcome of the study was the effect of different DDA methods on user experience. In addition, two secondary analyses were performed. First, the closed-loop classification accuracy was calculated for the 50 participants and correlated with the user experience. Second, the classifiers were retrained on the data from the 50 participants using the same methods as in the previous study.

**Effect of DDA Methods on User Experience**

The effect of the different DDA methods on user experience was assessed using two self-report questionnaires at the end of the 18-minute gameplay period: the Intrinsic Motivation Inventory (IMI) [47] and the Flow Experience Measure (FEM) [48]. The IMI is an 8-item questionnaire that assesses effort/importance, perceived competence, interest/enjoyment, and pressure/tension with two items per assessed variable. The same version was used in our previous exergaming research [35,36]. The FEM assesses a single, variable flow, using 8 items. This resulted in 5 outcome variables in total, which were compared between the methods using two-tailed two-sample t tests. Intrinsic motivation and flow are perhaps the two most commonly evaluated short-term outcomes of serious games and exercise [6,19,23,25,44,47] and were thus considered appropriate for this study.

**Accuracy of Speed and Paddle Size Changes**

In this study, three DDA methods (PE, PEPE, and all-data) used regression-based classifiers developed based on data from a previous study [33]. Their accuracy was defined as the percentage of agreement between the classifier’s opinion and the participant’s preference for changes in ball speed or paddle size (measured via the short questionnaire after each 2-minute gameplay interval). This accuracy was expected to correlate with user experience when the classifier was used as a basis for difficulty adjustment. In a previous study, the all-data method resulted in the most accurate classification, whereas PE resulted in the least accurate classification; however, the accuracies in this study may be different for multiple reasons. For example, the range of ball speeds in this study was wider than in the previous study, and new situations, even within the same scenario, may induce ungeneralizable physiological responses, significantly reducing classification accuracy [27]. Simply having new participants may also reduce classification accuracy, although this was expected to have a smaller influence as participants in this and previous studies were drawn from the same broad pool. Thus, the classification accuracy was recalculated for each DDA method using data from this study. To determine whether the accuracy of changes in ball speed and paddle size was correlated with user experience, Spearman correlation coefficients were calculated between each participant’s accuracy of ball speed and paddle size adjustments and the IMI and FEM outcomes. This was done across 40 participants; the manual group was dropped because they all had an accuracy of 100%.

**Classifier Retraining and Validation**

As mentioned in the previous subsection, we expected that the accuracy of the three classifiers used for the three DDA methods
(PE, PEPE, and all-data) would not be the same in this study as it was in the previous study [33]. Although the data collection in this study was performed with prebuilt classifiers, these classifiers could be retrained offline after the data collection conclusion to determine whether the all-data method is still the most accurate if validated on the new data.

To perform this training and revalidation, three combinations (PE, PEPE, and all-data) of the three data types (physiology, performance, and personality characteristics) from 80 participants (30 from a previous study and 50 from this study) were used as inputs to train classifiers that categorize perceived difficulty, enjoyment, desired change to ball speed, and desired change to paddle size (obtained from the short questionnaire) into three classes: low/decrease, medium/no change, and high/increase. Reference output values for all classifiers were obtained from the short questionnaire, and Table 1 presents the selected reference ranges of the short questionnaire answers for each class and variable. These ranges were chosen to provide the most even possible spread of samples among the three classes for each variable (although an even spread was not always feasible because of biases in the data). The current ball speed and paddle size were added to all input data combinations because they indicate the current game state and are available to any practical model.

Table 1. Defined ranges for retraining the three-class classifiers.

<table>
<thead>
<tr>
<th>Class</th>
<th>Difficulty</th>
<th>Enjoyment</th>
<th>Speed change</th>
<th>Paddle size change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1 to 2</td>
<td>1 to 4</td>
<td>−2 to −1</td>
<td>−2 to −1</td>
</tr>
<tr>
<td>Sample, n</td>
<td>180</td>
<td>246</td>
<td>62</td>
<td>151</td>
</tr>
<tr>
<td>Medium</td>
<td>3 to 5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sample, n</td>
<td>364</td>
<td>184</td>
<td>303</td>
<td>368</td>
</tr>
<tr>
<td>High</td>
<td>6 to 7</td>
<td>6 to 7</td>
<td>1 to 2</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Sample, n</td>
<td>176</td>
<td>290</td>
<td>355</td>
<td>355</td>
</tr>
</tbody>
</table>

To reduce the number of features before classification, stepwise forward feature selection [46] with an inclusion threshold of 0.05 was used to find the most informative set of features. Then, to classify the input data, four different classifiers were used: a support vector machine with a linear kernel, linear discriminant analysis, ensemble decision tree, and multiple linear regression. The classifiers were validated using 10-fold cross-validation (72 participants’ data used to train and 8 participants’ data to validate the classifier; the procedure was repeated 10 times with each participant in the validation data set once).

Results

Effects of DDA Methods on User Experience

All extracted features and questionnaire results are available in Multimedia Appendix 2. Figure 3 shows the five outcomes of the IMI and FEM for all five DDA methods, presented as a violin plot of the 10 participants assigned to each method. The outcomes of the IMI and FEM were compared between different DDA methods using two-tailed two-sample t tests; however, only one difference was significant: pressure/tension was higher in the all-data method than in the random method (P=.04).
Figure 3. Violin plot of postexperiment self-report questionnaire outcomes. All data: based on physiology, personality, and performance. Each participant is indicated as a dot. The first four questionnaire outcomes have a possible range of 2-14, whereas flow has a possible range of 8-40. PE: adjustment based on performance; PEPE: adjustment based on personality and performance.

Classifier Accuracy and Retraining

Table 2 shows the accuracy of each DDA method in the dynamic prediction of the participants’ desired changes to the game difficulty parameters. Accuracy was calculated by comparing the classifier’s prediction and the participants’ preference expressed on the short questionnaire after all 2-minute intervals. The manual method trivially achieves 100% accuracy because it uses the participants’ answers as a basis for difficulty adjustment. Among the other four methods, the all-data method was the most accurate for predicting the desired adjustments to ball speed and paddle size.

Figure 4 depicts the ball speed and paddle size for nine 2-minute intervals of each DDA method.

Table 3 presents the accuracies of three-class classification of the four answers to the short questionnaire when retraining and validating the classifiers using three combinations of input data types obtained from 80 participants. Combining all data types (all-data) resulted in the most accurate classifiers.

Table 2. Prediction accuracy of changes to the game difficulty parameters.

<table>
<thead>
<tr>
<th>Difficulty parameter</th>
<th>Difficulty adjustment method (%)</th>
<th>Manual</th>
<th>Random</th>
<th>PE&lt;sup&gt;a&lt;/sup&gt;</th>
<th>PEPE&lt;sup&gt;b&lt;/sup&gt;</th>
<th>All-data&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball speed</td>
<td></td>
<td>100</td>
<td>32.5</td>
<td>53.7</td>
<td>43.7</td>
<td>62.5</td>
</tr>
<tr>
<td>Paddle size</td>
<td></td>
<td>100</td>
<td>41.2</td>
<td>46.2</td>
<td>33.5</td>
<td>55.0</td>
</tr>
</tbody>
</table>

<sup>a</sup>Based on performance.

<sup>b</sup>Based on personality and performance.

<sup>c</sup>Based on physiology, personality, and performance.
Figure 4. Ball speed (left) and paddle size (right) of five dynamic difficulty adjustment methods for nine 2-minute game intervals across 10 participants. Error bars indicate 95% CI. PE: based on performance; PEPE: based on personality and performance; all data: based on physiology, personality, and performance.

Table 3. Mean three-class classification accuracies for different combinations of input data modalities.

<table>
<thead>
<tr>
<th>Input data</th>
<th>Outcome variable (%)</th>
<th>Difficulty</th>
<th>Enjoyment</th>
<th>Speed change</th>
<th>Paddle size change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE(^a)</td>
<td>62.4 (S(^b))</td>
<td>50.2 (L(^c))</td>
<td>64.6 (E(^d))</td>
<td>55.8 (E)</td>
<td></td>
</tr>
<tr>
<td>PEPE(^e)</td>
<td>62.5 (S)</td>
<td>50.7 (S)</td>
<td>62.9 (S)</td>
<td>59.9 (R(^f))</td>
<td></td>
</tr>
<tr>
<td>All-data</td>
<td>64.2 (S)</td>
<td>50.7 (S)</td>
<td>62.6 (E)</td>
<td>61.7 (R)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Based on performance.  
\(^b\)S: support vector machine.  
\(^c\)L: linear discriminant analysis.  
\(^d\)E: ensemble decision tree.  
\(^e\)Based on personality and performance.  
\(^f\)R: multiple linear regression.

Correlation Between Classifier Accuracy and User Experience

Finally, Table 4 presents the Spearman correlation coefficients of the outcomes of the IMI and FEM questionnaires and the accuracy of ball speed and paddle size adjustments across all DDA methods except manual (where it was always 100%).


Discussion

Practical Implications

No differences were observed between the DDA methods. The exception was higher pressure/tension with the all-data method than with the random method, which was expected as the all-data method resulted in greater difficulty (Figure 4); similar higher pressure/tension as a result of adaptation versus no adaptation has been observed in our previous work [35]. Although we shall discuss the limitations of this study later, we first discuss the practical implications of the results.

As there was no clear benefit to the all-data method, our results do not support the use of physiological measurements for affective exergaming in practical environments. Physiological sensors are expensive, time-consuming, and inconvenient; thus, they should not be used unless they show a clear benefit. This result disagrees with the study of Xu et al [14], which found positive effects of physiology-based DDA, but it is difficult to compare the 2 studies because of significant methodological differences; for example, the Xu study had only three difficulty levels in total. At first, the result also appears to disagree with a previous study by Liu et al [8], which found positive effects of physiology-based DDA in an entertainment game. However, Liu et al [8] also did not find significant differences between physiology-based DDA and performance-based DDA based on outcome measures obtained at the end of the session; they were only able to show a difference because outcome measures were also obtained at multiple time points during gameplay itself, and those midgame outcomes were significant.

The prediction accuracy of changes to game difficulty parameters was higher with the all-data method than all other automated methods (Table 2), so the inclusion of physiological measurements did increase accuracy. For example, the accuracies for ball speed and paddle size were 62.5% and 55.0% with the all-data method compared with 53.7% and 46.2% with the PE method, respectively. The difference in accuracy may have been too low to improve the user experience meaningfully. Our previous Wizard of Oz study, for example, found that users did not reliably perceive a difference between psychological state classification accuracies that differed by less than 10% [30]. Thus, other games where adding physiological measurements increased DDA accuracy by less than 10% (including our own previous work [12] and the work of Chanel et al [9]) also may not find an improvement in user experience as a result.

As seen in Table 4, the accuracy of DDA correlated with user enjoyment/interest ($r=0.38; P=0.01$) when the four nonmanual DDA groups were pooled together. This result agrees with our previous research [29,30] and with studies from other authors [28]. Thus, our study supports the value of more effective, personalized DDA methods; it simply does not support the premise that physiology-based DDA will be more effective than performance-based DDA.

Finally, a follow-up analysis was conducted to identify any clear patterns in when and how the DDA methods made mistakes. A clear pattern was observed: all DDA methods were more accurate at extreme difficulties (eg, very high/low paddle sizes) than at moderate difficulties. This is, in our opinion, unsurprising: when the difficulty is set to an extreme level, the correct choice is very likely to be moving away from the extreme. However, when difficulty is moderate, the correct choice is more dependent on the individual player.

Differences in Classifier Performance

Three DDA methods used classifiers that were trained on data from a previous open-loop study [33]. Studies from other fields of human-machine interaction have shown that classifiers that perform well in an offline, open-loop setting may not perform equally well in an online, real-time setting where they are used to influence machine behavior [31,32]. Thus, although our primary research focus was on user experience, we were also interested in whether the previously trained classifiers would exhibit lower accuracy in this study. Indeed, the accuracies in this study (Table 3) were lower than those in the previous one. For example, in the previous study, the all-data method resulted in a classification accuracy of 84.1% for both ball speed and paddle size preferences [33]; in this study, the accuracies were 62.5% for ball speed and 55% for paddle size. As a validation step, we reran the classification offline (post hoc) to ensure there was no bug with real-time processing; this resulted in the same results as during the data collection sessions.

We believe that the primary reason for the decrease in classification accuracy is the difference in the experienced situations. In a previous study [33], participants were exposed to three different ball speeds and three paddle sizes. In this study, participants were exposed to six different ball speeds and four paddle sizes. This is partially a weakness of our study design; however, in realistic applications, physiological state
classification algorithms would inevitably be exposed to situations not seen in the training data. As a follow-up analysis, we retrained and evaluated the same types of classifiers using data from all 50 participants in this study and the 30 participants from the previous one (80 participants in total). As shown in Table 3, this also resulted in lower accuracies than those in the previous study [33], and we again believe that the primary reason for the difference was the broader range of experienced situations.

Nonetheless, as another practical implication, this result suggests that psychological state classification accuracies obtained during offline classifier training on previously recorded data may not transfer to a real-time DDA context. Thus, although a higher DDA accuracy correlates with user experience (Table 4), any exergame studies that only show differences in offline classification accuracy (including our own previous work [33]) should be taken with a grain of salt because these offline results are not guaranteed to have practical benefits when applied to DDA.

Could Other Study Designs Be More Sensitive?

As our study did not show differences in user experience among the DDA methods, we must ask whether other study designs would be more sensitive to these differences. Indeed, an intuitive follow-up study would be to test the same DDA methods in a within-subjects design, with each participant experiencing multiple DDA methods. Xu et al [14] and Liu et al [8] found differences in user experience between physiology-based and performance-based DDA, both of which used a within-subjects design, similar to our previous Wizard of Oz study [30]. In this study, we opted for a between-subjects design so that participants could experience their assigned DDA method for a longer amount of time; using multiple DDA methods would have resulted in much longer sessions. However, we acknowledge that this is not necessarily optimal.

Instead of a within-subjects design, it would also be possible to increase the sample size. The 10 participants assigned to each DDA method in this study constitute a relatively small sample size that may have been insufficient to find differences even if they did exist. We originally envisioned a larger sample size; however, data collection was carried out in early 2020 and then interrupted by the COVID-19 pandemic, forcing us to limit ourselves to the collected 50 participants.

Finally, in addition to a within-subjects design and/or a larger sample size, additional qualitative data could have been collected. For example, players could have been asked open-ended questions about their experiences. This data collection was done in the study by Liu et al [8], where participants reported lower anxiety with physiology-based DDA in open-ended questions but did not report lower anxiety on postgame forced-choice questionnaires. Although no systematic qualitative data collection was performed in this study, we mention an experimenter observation: although participants did not know which DDA method they had been assigned to, some appeared to have initial biases (eg, whether useful information can be extracted from physiology), and some attempted to determine whether their physiology influenced the system by, for example, breathing rapidly. This is in line with previous publications about participant bias and bidirectional relationships in affective computing [27,28] and may warrant further investigation.

Limitations of the Used Exergame

Finally, the results of our study do not necessarily generalize to all affective exergames. We believe that the choice of three-class classification followed by increasing or decreasing or not changing difficulty is not controversial, as it represents a classic approach to affective gaming [21]. However, our study adjusted two difficulty parameters (ball speed and paddle size) simultaneously, and the results may not be generalizable to games where only a single difficulty parameter is changed, such as in the work of Liu et al [8]. Furthermore, our study changed difficulty in relatively small steps, and our results may not generalize to games where a single DDA decision may immediately change the difficulty to a very high or very low level, such as in the work of Xu et al [14].

In addition, our study is based on the classic affective gaming approach of classifying difficulty based on prerecorded data and then adapting it at a constant frequency without user input [21]. Thus, it may not generalize to designs where DDA is adapted with a variable frequency, although such designs are not yet common in affective computing; it also may not generalize to designs where users can provide feedback about DDA decisions, potentially increasing future accuracy. For example, reinforcement learning, which remains largely unexplored in affective exergames, could be used for this purpose—users could give rewards for correct DDA decisions, gradually leading to a more positive user experience. Furthermore, the results may not generalize to designs that omit classification entirely and use other schemes, such as fuzzy control [5] or random forest–based regression [16].

Finally, different results might be obtained in the same scenario using different data analysis methods. For example, improved physiological feature extraction and classification may increase the accuracy of physiology-based DDA, resulting in an improved user experience in the same setting; conversely, improved performance feature extraction may also increase the accuracy of performance-based DDA. If we were to reuse the data for further research, we would likely first investigate alternatives to stepwise feature selection, which has potential issues and may not select the optimal subset of features [49]. As a follow-up analysis, we retrained and evaluated the same classifiers with two different feature reduction methods (principal component analysis and the lasso method, recommended by an article critiquing stepwise methods [49]) but did not find an improvement in classification accuracy as a result of these methods.

Conclusions

Five aspects of user experience were compared among five DDA methods of a Pong exergame: manual, random, PE, PEPE, and all-data. The last three methods adjusted the ball speed and paddle size in the game using regression-based classifiers developed in a previous (open-loop) study with 30 participants. Though the all-data method exhibited the highest user state classification accuracy (approximately 10% higher than the PE
method), no significant differences in user experience were observed among DDA methods. Thus, our results do not support the addition of physiological measurements to affective exergames; as such measurements are expensive and time-consuming, they should only be added if they meaningfully improve user experience. The study found that user experience was correlated with user state classification accuracy, thus supporting the development of more effective DDA methods, which simply does not support the notion that additional measurements will automatically improve the user experience.

The study results are limited by a somewhat suboptimal study design: each participant experienced only one DDA method, and a within-subjects design in which participants experience multiple methods may find positive effects of more complex DDA methods on user experience. Nonetheless, few studies have examined the relative effects of physiology-based DDA on user experience, and our study thus adds to the limited body of evidence on the effects of physiological measurements in affective games on user experience.

Acknowledgments
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Authors’ Contributions
AD led the data collection and analysis and wrote most of the manuscript. SMM contributed to the literature review, study design, and data analysis. DN supervised the entire study, led the study design, and contributed to data analysis and manuscript writing. All authors read and approved the final manuscript.

Conflicts of Interest
None declared.

Multimedia Appendix 1
Details about physiological measurements, questionnaires, and linear regression–based models. [DOC File, 104 KB - games_v9i2e25771_app1.doc ]

Multimedia Appendix 2
Results from individual participants in each game condition. [XLS File (Microsoft Excel File), 965 KB - games_v9i2e25771_app2.xls ]

References


Abbreviations

DDA: dynamic difficulty adjustment  
ECG: electrocardiogram  
EEG: electroencephalography  
FEM: Flow Experience Measure  
IMI: Intrinsic Motivation Inventory  
PE: performance based  
PEPE: personality-performance based
Impact of Gamification on the Self-Efficacy and Motivation to Quit of Smokers: Observational Study of Two Gamified Smoking Cessation Mobile Apps

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Abstract

Background: The proportion of smokers making quit attempts and the proportion of smokers successfully quitting have been decreasing over the past few years. Previous studies have shown that smokers with high self-efficacy and motivation to quit have an increased likelihood of quitting and staying quit. Consequently, further research on strategies that can improve the self-efficacy and motivation of smokers seeking to quit could lead to substantially higher cessation rates. Some studies have found that gamification can positively impact the cognitive components of behavioral change, including self-efficacy and motivation. However, the impact of gamification in the context of smoking cessation and mobile health has been sparsely investigated.

Objective: This study aims to examine the association between perceived usefulness, perceived ease of use, and frequency of use of gamification features embedded in smoking cessation apps on self-efficacy and motivation to quit smoking.

Methods: Participants were assigned to use 1 of the 2 mobile apps for a duration of 4 weeks. App-based questionnaires were provided to participants before app use and 2 weeks and 4 weeks after they started using the app. Gamification was quantitatively operationalized based on the Cugelman gamification framework and concepts from the technology acceptance model. The mean values of perceived frequency, ease of use, and usefulness of gamification features were calculated at midstudy and end-study. Two linear regression models were used to investigate the impact of gamification on self-efficacy and motivation to quit.

Results: A total of 116 participants completed the study. The mean self-efficacy increased from 37.38 (SD 13.3) to 42.47 (SD 11.5) points and motivation to quit increased from 5.94 (SD 1.4) to 6.32 (SD 1.7) points after app use. Goal setting was perceived to be the most useful gamification feature, whereas sharing was perceived to be the least useful. Participants self-reported that they used the progress dashboards the most often, whereas they used the sharing feature the least often. The average perceived frequency of gamification features was statistically significantly associated with change in self-efficacy ($\beta$=3.35; 95% CI 0.31-6.40) and change in motivation to quit ($\beta$=.54; 95% CI 0.15-0.94) between baseline and end-study.

Conclusions: Gamification embedded in mobile apps can have positive effects on self-efficacy and motivation to quit smoking. The findings of this study can provide important insights for tobacco control policy makers, mobile app developers, and smokers seeking to quit.

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KEYWORDS
gamification; smoking cessation; mobile applications; self-efficacy; motivation to quit; mHealth; mobile phone
Introduction

Smoking is the second leading risk factor for early death and disability worldwide, with approximately 8 million deaths annually [1,2]. In the United Kingdom, 16% of all deaths in 2016 were attributed to smoking [3]. Despite most smokers wanting to quit, research shows that the number of smokers in the United Kingdom who tried to quit in the past year dropped by 7% between 2008 and 2017 [4]. Among the smokers making attempts, only 3%-5% are successful in staying quit after a year [5]. Exploring methods that can improve the success rates of long-term quitting can lead to a decreased prevalence of chronic diseases and premature mortality. Previous studies have shown that high motivation to quit and self-efficacy, 2 factors often integrated into face-to-face behavioral support interventions, have been found to increase the likelihood of attempting to quit and successfully quitting [6-9].

Motivation to quit refers to the level of determination and importance placed by an individual on quitting smoking [10]. On the other hand, self-efficacy, a theoretical construct first termed by Bandura [11], in the context of smoking cessation refers to one’s confidence in their ability to refrain from smoking when faced with internal and external stimuli [11,12]. Several strategies are adopted by health behavior change interventions to influence self-efficacy or motivation to quit. For example, motivational interviewing is often used to help smokers explore reasons for quitting and “make them feel more willing and able to stop smoking” [13]. Similarly, vicarious experience and performance attainment are strategies to influence self-efficacy. Vicarious experience involves “exposing the individual to successful behaviour performances or gaining experience through practice” [14]. In the context of smoking cessation, this could mean showing smokers examples of other smokers who successfully quit after attending cessation programs. Performance attainment refers to having successful experiences [11,14]; for a smoker trying to quit, this could mean staying abstinent for a day and recognizing this as a success. Such strategies have been integrated into both face-to-face and digital interventions, such as mobile health (mHealth) solutions, which have become increasingly important to improve access, knowledge, and behavior across different contexts and population groups [15].

One strategy that has been frequently applied across both physical and remote interventions for behavioral change is gamification, also known as the use of game elements in a nongame context [16]. Some examples of game elements include achievement badges, goal setting, progress tracking, sharing progress, and levels [17]. Past studies have found that gamification can positively impact cognitive components of behavioral change, including self-efficacy and motivation. For example, self-efficacy was the most cited advantage of gamified classrooms, as it improved the confidence levels of students [18]. Similarly, Thorsteinset al [19] found that gaming elements significantly increased the motivation of individuals to engage in physical activity. The use of gamification has gradually become more popular as it appears to share key components with several behavioral change theories and techniques [17,20]. For example, self-determination theory, a dominant theory of motivation, suggests that gamification elements such as points and badges serve as informational feedback instilling a sense of intrinsically motivating competence in the user [21]. Similarly, goal-setting theory, another prominent theory of motivation, has been associated with gamification; for example, elements such as leaderboards and levels provide individuals with smaller, more immediate goals that can improve task performance and, in turn, increase one’s confidence in their ability to complete tasks [21,22].

Although gamification seems promising, the impact of gamification in the field of health behavior change has focused primarily on improving physical activity levels [23-25]. More specifically, there is room to further study the use of gamification in the context of other behaviors, such as smoking. With the proliferation of smartphone use and the increased availability of digitalized interventions, it is vital to investigate novel strategies, such as gamification, that complement mHealth solutions and are in line with current digitalization trends. The majority of studies that have explored the impact of gamification in the context of smoking cessation have been purely qualitative and consequently have not operationalized gamification quantitatively. For example, Pløhn and Aalberg [26] interviewed participants after they used a digital smoking cessation intervention with gamification features and found positive perceptions of gamification as an important motivational factor to aid quitting. However, the smoking cessation intervention was not delivered via a mobile app. Another study by El-Hilly et al [27] found promising results on the effect of gamification on the motivation and engagement of smokers within the context of mHealth. Similar to the study by Pløhn and Aalberg [26], the study by El-Hilly et al [27] was also qualitative and had a small sample size (n=16), hindering the external validity of the findings. On the other hand, Lin et al [28] investigated gamification quantitatively and found that program progress or step completion as a gamification element in a smoking cessation mobile app had a positive impact on psychological factors such as user well-being, inspiration, and empowerment [28]. It would be worthwhile to investigate whether gamification in smoking cessation apps can also positively impact essential cognitive factors such as self-efficacy and motivation to quit. Exploring whether gamification in the context of mHealth can increase the self-efficacy and motivation of smokers could lead to the design of more tailored interventions, which, in turn, could improve cessation rates and reduce the health burden of tobacco consumption. The findings of this study could also provide insights into the effective design of mobile apps. Moreover, because of the wide reach and low cost of mHealth solutions, understanding the effects of gamification on mHealth could have considerable effects on helping disadvantaged groups and reducing health inequalities [29]. On the basis of the limitations of prior research, this study’s aim of exploring gamified smoking cessation apps can also help enhance the current understanding of the effectiveness of mHealth interventions for behavior change and extend our knowledge of novel methods to promote healthy lifestyle changes. Specifically, our study aims to quantitatively assess the association between overall perceived usefulness, ease of use,
and frequency of use of gamification features and the self-efficacy and motivation of smokers seeking to quit.

Methods

Sampling and Eligibility

On the basis of an a priori analysis using a power level of $1-\beta=.80$ and a significance level $\alpha=.05$, we aimed to recruit 140 participants. The results of a previous study examining the impact of gamification elements in a fitness app on perceived competence, a proxy for self-efficacy, indicated that 112 participants were required to complete the study [25]. Similar to previous mobile app studies, we considered a dropout rate of approximately 20% [30-32], which resulted in the recruitment of 140 participants. The sample size calculation also assumes that both apps are similar based on a prior mobile app review [33].

Participants were required to be at least 18 years old and current smokers (at least one cigarette a day and 100 cigarettes smoked in their lifetime) to be eligible. Moreover, to take part in the study, individuals had to report that they were trying or willing to quit smoking in the next 30 days and were not using other forms of smoking cessation treatments. Individuals diagnosed with mental health conditions were excluded from the study.

Study Design

A 4-week observational study assessing the association between gamification, self-efficacy, and motivation to quit was conducted from June 2019 to July 2020. No face-to-face contact was required, and the study was conducted online. Participants were recruited via social media, and posters were displayed in public places in London. Initially, participants who expressed interest in the study (N=326) were screened to assess their eligibility. Eligible participants provided informed consent (n=170) and were assigned a participant identification number (PID). They were then requested to complete a baseline questionnaire that asked about general demographics (age, gender, education, marital status, education, country of residence, etc), smoking habits (number of cigarettes smoked, nicotine dependence, etc), self-efficacy, and motivation to quit.

In total, 154 participants completed the baseline assessment and were provided instructions on how to download and start using the app. Even-numbered PIDs were assigned to the mobile app Quit Genius, and odd-numbered PIDs were assigned to the mobile app Kwit. This deterministic method was used to ensure an equal split of participants between the 2 apps. Participants were asked to use the assigned mobile app for a total of 4 weeks. A midstudy questionnaire after 2 weeks of using the app and an end-study questionnaire after 4 weeks of using the app were given to participants.

Of those participants who completed the baseline assessment, 138 installed the app and 116 completed all 4 weeks of the study. Midstudy and end-study assessments included questions regarding gamification, self-efficacy, and motivation to quit. Participants were incentivized via free access to all features of the app and a chance to win a £50 (US $68) Amazon voucher. An overview of the number of participants at each stage of the study is presented in Multimedia Appendix 1.

Mobile Apps

Mobile apps for the study were selected based on a mobile app review that found these 2 apps to have a high embedment of gamification features and a high adherence to smoking cessation guidelines in the United Kingdom [33,34]. Screenshots of both apps are shown in Multimedia Appendix 2.

Kwit

Kwit is a smoking cessation mobile app that helps individuals starting their quit journey and individuals trying to stay quit [35]. The app includes several features such as a calculator, a smoking diary that helps smokers log and analyze cravings and triggers, motivation cards, social media sharing, levels, and achievement cards. The app is based on cognitive behavioral therapy (CBT) and gamification strategies. The versions of Kwit used during the study period included those released from June 2019 (v.4.1) to July 2020 (v.4.4).

Quit Genius

Quit Genius is a gamified smoking cessation mobile app based on CBT [36]. It delivers personalized support to individuals seeking to quit smoking and helps quitters maintain their quit status. It includes several features such as a tracker, a daily diary that allows quitters to log their cravings and triggers, a quitting toolbox, a goal-setting feature, achievement badges, stages of information that build upon each other, and a quit coach who provides continuous personalized support. The versions downloaded by participants were those released from June 2019 (v.1.1) to July 2020 (v.1.9).

Measures

Sociodemographic Factors

Common sociodemographic factors were assessed at baseline. Age in years was categorized as 18-29, 30-41, 42-53, or 54-65 years, and gender was categorized as male or female. Marital status was categorized as single or married or civil partnered. Education was based on United Nations Educational, Scientific and Cultural Organization’s classification into 3 categories: low if primary school was completed, medium if secondary school was completed, and high if a college or university degree was attained [37]. Employment status was categorized as unemployed (individuals who are willing and able to work but have no employment), employed, or nonemployed (individuals who are unable to work, including students and homemakers). Residence was categorized based on the World Health Organization regions: Western Pacific, Americas, Southeast Asia, Europe, Africa, and Eastern Mediterranean [38].

Nicotine Dependence

The Fagerström test with 6 items was used to measure participants’ tolerance of and dependence on nicotine [36]. On the basis of the responses, participants were categorized into 3 levels: low (0-4 points), moderate (5-7 points), and high (8-10 points) [39,40].

Self-Efficacy

The self-efficacy of a participant was measured using a 12-item scale called The Smoking Self-Efficacy Questionnaire [12]. The scale assesses an individual’s confidence in their ability to
refrain from smoking when faced with internal and external stimuli. Response options included not at all sure, not very sure, more or less sure, fairly sure, and absolutely sure. A total score ranging from 12 to 60 was computed for each participant, with higher scores signifying higher self-efficacy.

**Motivation to Quit**

Participants were asked 2 items frequently used in cessation studies to measure their motivation to quit smoking [10,41,42]. The first item asked was as follows: How important is it to you to give up smoking altogether at this attempt? Responses included the following: desperately important, very important, quite important, and not all that important. The second item asked was as follows: How determined are you to give up smoking at this attempt? Response options included the following: extremely determined, very determined, quite determined, and not all that determined. A total score ranging from 2 to 8 was calculated for each participant, with higher scores signifying higher motivation.

**Gamification**

Gamification features for each app were identified using Cugelman framework for gamification strategies and tactics and are displayed in Multimedia Appendix 3 [17]. For each identified gamification feature, participants were asked how useful and easy to use they found it during their quit attempt. Participants were provided with 5-point Likert scale responses: strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree. Perceived usefulness and ease of use are 2 vital components of the technology acceptance model, which has been widely used in existing literature to better understand user acceptance and attitudes toward mobile apps and app features [43,44].

Participants were also asked how frequently they engaged with each gamification element or feature during their quit attempt. Participants were provided with 5-point Likert scale responses: almost always, often, sometimes, rarely, and never. Responses were assigned points ranging from 1 to 5 for each gamification feature. A pooled mean was calculated for all features, with a higher mean (from 1 to 5) indicating greater overall engagement with gamification.

**Statistical Analysis**

The statistical software STATA 13.1 (StataCorp), was used for the analyses. Box and whisker plots were created to present an overview of self-efficacy and motivation to quit levels of participants at various study time points. The mean values of perceived frequency, ease of use, and usefulness of gamification features were calculated at midstudy and end-study. Two-way paired sample t tests were used to test whether differences in self-efficacy and motivation to quit at various time points of the study were statistically significant. In addition, we explored various linear regression models to examine whether gamification was associated with changes in self-efficacy and motivation to quit. On the basis of an iterative process that considered the fit of the data with our model (ie, comparing the Akaike information criterion and Bayesian information criterion), 2 linear regression models were performed. The first tested the association between perceived ease of use, frequency of use, and usefulness of gamification with change in self-efficacy, and the second tested the association between perceived ease of use, frequency of use, and usefulness of gamification with change in motivation to quit. Both models controlled for age, gender, education, marital status, nicotine dependence, baseline self-efficacy, and baseline motivation to quit. Significance at the 5% level (0.05), along with 95% CIs for all included coefficients, is presented in the Results section.

**Results**

**Study Participants**

As shown in Table 1, there was an equal split of participants who used the apps Kwit (58/116, 50%) and Quit Genius (58/116, 50%). The majority of participants were male (71/116, 61.2%), highly educated (87/116, 75%), single (77/116, 66.4%), employed (76/116, 65.6%), and living in Europe (67/116, 57.8%). More than half of the participants smoked 10 or fewer cigarettes on a daily basis (63/116, 54.3%), and the majority had low to moderate dependence on nicotine (107/116, 92.2%).
Table 1. Sociodemographic and general characteristics of participants (n=116).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Respondents, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assigned mobile app</strong></td>
<td></td>
</tr>
<tr>
<td>Kwit</td>
<td>58 (50)</td>
</tr>
<tr>
<td>Quit Genius</td>
<td>58 (50)</td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td></td>
</tr>
<tr>
<td>18-29</td>
<td>49 (42.2)</td>
</tr>
<tr>
<td>30-41</td>
<td>41 (35.3)</td>
</tr>
<tr>
<td>42-53</td>
<td>15 (12.9)</td>
</tr>
<tr>
<td>54-65</td>
<td>11 (9.5)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>71 (61.2)</td>
</tr>
<tr>
<td>Female</td>
<td>45 (38.8)</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
</tr>
<tr>
<td>Low (primary school)</td>
<td>8 (6.9)</td>
</tr>
<tr>
<td>Medium (secondary school)</td>
<td>21 (18.1)</td>
</tr>
<tr>
<td>High (university or college degree)</td>
<td>87 (75)</td>
</tr>
<tr>
<td><strong>Marital status</strong></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>77 (66.4)</td>
</tr>
<tr>
<td>Married or civil partnered</td>
<td>39 (33.6)</td>
</tr>
<tr>
<td><strong>Employment status</strong></td>
<td></td>
</tr>
<tr>
<td>Employed</td>
<td>76 (65.6)</td>
</tr>
<tr>
<td>Nonemployed</td>
<td>31 (26.7)</td>
</tr>
<tr>
<td>Unemployed</td>
<td>6 (5.2)</td>
</tr>
<tr>
<td>Prefer not to answer</td>
<td>3 (2.6)</td>
</tr>
<tr>
<td><strong>World Health Organization regions</strong></td>
<td></td>
</tr>
<tr>
<td>Western Pacific</td>
<td>4 (3.4)</td>
</tr>
<tr>
<td>Americas</td>
<td>10 (8.6)</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>16 (13.8)</td>
</tr>
<tr>
<td>Europe</td>
<td>67 (57.8)</td>
</tr>
<tr>
<td>Africa</td>
<td>17 (14.7)</td>
</tr>
<tr>
<td>Eastern Mediterranean</td>
<td>2 (1.7)</td>
</tr>
<tr>
<td><strong>Daily smoking (number of cigarettes)</strong></td>
<td></td>
</tr>
<tr>
<td>10 or less</td>
<td>63 (54.3)</td>
</tr>
<tr>
<td>11-20</td>
<td>43 (37.1)</td>
</tr>
<tr>
<td>21-30</td>
<td>8 (6.9)</td>
</tr>
<tr>
<td>31 or more</td>
<td>2 (1.7)</td>
</tr>
<tr>
<td><strong>Fagerström nicotine dependence</strong></td>
<td></td>
</tr>
<tr>
<td>Low (0–4)</td>
<td>62 (53.4)</td>
</tr>
<tr>
<td>Moderate (5–7)</td>
<td>45 (38.8)</td>
</tr>
<tr>
<td>High (8–10)</td>
<td>9 (7.8)</td>
</tr>
</tbody>
</table>
Self-Efficacy and Motivation to Quit

Figure 1 shows that the mean motivation to quit increased from 5.94 at baseline to 6.20 after 2 weeks of app use and to 6.32 points after 4 weeks of app use. The median motivation to quit (and IQR) at baseline was 6.00 (IQR 5–7), 6.00 (IQR 5–8) at 2 weeks, and 7.00 (IQR 5–8) at 4 weeks. Similarly, the mean self-efficacy score increased from 37.38 points at baseline to 41.37 points after 2 weeks of using the app and then to 42.47 points after 4 weeks of using the app. Median self-efficacy (and IQR) at baseline was 37.00 (IQR 5-7), which increased to 42.50 points (IQR 33-50) at 2 weeks and increased further to 44.00 (IQR 35-51) at 4 weeks. Paired t tests found that increases in mean self-efficacy and motivation to quit between baseline and midstudy and baseline and end-study were statistically significant (Multimedia Appendix 4).

Figure 1. Self-efficacy and motivation to quit at baseline, midstudy, and end-study (n=116).

Gamification

Table 2 displays the average midstudy and end-study perceived usefulness, ease of use, and frequency of use of overall gamification and specific gamification features embedded in the apps. At midstudy and end-study, goal setting was perceived to be the most useful gamification feature (4.14 score out of 5), whereas sharing was perceived to be the least useful feature (3.72 at midstudy and 3.28 at end-study out of 5). Participants also perceived goal setting to be the easiest to use feature at both midstudy and end-study (4.31 and 4.36, respectively). In terms of frequency of use, participants self-reported that they used the progress dashboards the most often during both the midstudy and end-study assessments (3.23 and 3.30, respectively). The feature reported to be used the least frequently was the sharing feature, as not many participants shared their progress or results with others.

The linear regression model results presented in Table 3 show that a 1-point increase in average perceived frequency of gamification features was statistically significantly associated with a 3.35-point increase in self-efficacy from baseline to end-study (β=3.35; 95% CI 0.31-6.40). The average perceived ease of use and usefulness of gamification were not associated with changes in self-efficacy. In addition, a 1-point increase in baseline self-efficacy was associated with a 1.06-point decrease in self-efficacy between baseline and end-study (β=−1.06; 95% CI −1.22 to −0.90). Gender, marital status, nicotine dependence, baseline motivation, average perceived ease of use, and usefulness of gamification features were not statistically significantly associated with changes in self-efficacy from baseline to end-study. The second linear regression model presented in Table 3 shows that individuals with medium or high education had, on average, a 1.31 point (95% CI −2.60 to −0.01) and 1.21 point (95% CI −2.32 to −0.10) lower motivation to quit than individuals with a low level of education. Moreover, a 1-point increase in average perceived frequency of use of gamification features was statistically significantly associated with a 0.54-point increase in motivation to quit at end-study compared with baseline (β=.54; 95% CI 0.15-0.94). Similarly, there was some indication that the average usefulness of gamification and baseline self-efficacy are associated with change in motivation to quit. Finally, a 1-point increase in baseline motivation to quit was statistically significantly associated with a 0.69-point decrease in motivation to quit (β=−.69; 95% CI −0.90 to −0.49).
Table 2. Overview of perceived frequency of use, ease of use, and usefulness of gamification features embedded in the Kwit and Quit Genius apps (n=116).

<table>
<thead>
<tr>
<th>Gamification features</th>
<th>Mid-study, mean (SD)</th>
<th>End-study, mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perceived usefulness</td>
<td>Perceived ease of use</td>
</tr>
<tr>
<td>Logging diaries</td>
<td>3.78 (0.99)</td>
<td>4.08 (0.95)</td>
</tr>
<tr>
<td>Achievements and badges</td>
<td>3.64 (1.11)</td>
<td>3.91 (0.96)</td>
</tr>
<tr>
<td>Progress tracking</td>
<td>3.91 (0.94)</td>
<td>4.07 (0.86)</td>
</tr>
<tr>
<td>Unlocking levels or competing stages</td>
<td>3.93 (0.89)</td>
<td>4.01 (0.94)</td>
</tr>
<tr>
<td>Sharing feature</td>
<td>3.08 (1.15)</td>
<td>3.72 (0.87)</td>
</tr>
<tr>
<td>Motivation cards</td>
<td>3.64 (0.95)</td>
<td>4.10 (0.79)</td>
</tr>
<tr>
<td>Goal setting</td>
<td>4.14 (0.85)</td>
<td>4.31 (0.71)</td>
</tr>
<tr>
<td>Overall</td>
<td>3.71 (0.75)</td>
<td>4.00 (0.64)</td>
</tr>
</tbody>
</table>

aRange: 1-5.
bOnly applicable to Kwit.
cOnly applicable to Quit Genius.

Table 3. Linear regression model examining the association between perceived usefulness, ease of use, and frequency of use of gamification features with change in self-efficacy and change in motivation to quit (n=116).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Change in self-efficacy</th>
<th>Change in motivation to quit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>95% CI</td>
</tr>
<tr>
<td>Age (years)</td>
<td>−.05</td>
<td>−0.26 to 0.17</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (referent)</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Female</td>
<td>1.89</td>
<td>−2.48 to 6.26</td>
</tr>
<tr>
<td>Nicotine dependence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (referent)</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Moderate</td>
<td>−1.02</td>
<td>−5.50 to 3.46</td>
</tr>
<tr>
<td>High</td>
<td>5.93</td>
<td>−2.15 to 14.02</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (referent)</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Medium</td>
<td>−4.95</td>
<td>−15.01 to 5.16</td>
</tr>
<tr>
<td>High</td>
<td>−8.01</td>
<td>−16.63 to 0.61</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single (referent)</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Married</td>
<td>−.10</td>
<td>−5.35 to 5.17</td>
</tr>
<tr>
<td>Mean frequency of gamification use</td>
<td>3.35^a</td>
<td>0.31 to 6.40</td>
</tr>
<tr>
<td>Mean ease of use of gamification</td>
<td>−1.21</td>
<td>−5.16 to 2.74</td>
</tr>
<tr>
<td>Mean usefulness of gamification</td>
<td>1.63</td>
<td>−2.53 to 5.79</td>
</tr>
<tr>
<td>Baseline self-efficacy</td>
<td>−1.06^a</td>
<td>−1.22 to −0.90</td>
</tr>
<tr>
<td>Baseline motivation to quit</td>
<td>1.14</td>
<td>−0.44 to 2.71</td>
</tr>
<tr>
<td>Constant</td>
<td>35.79^a</td>
<td>15.68 to 53.89</td>
</tr>
</tbody>
</table>

^aP<.05.
Discussion

Principal Findings

We found that the use of Kwit and Quit Genius was associated with increased self-efficacy and motivation to quit smoking after 4 weeks of app use compared with baseline. Our study also found that the perceived frequency of use of gamification features was associated with an increase in self-efficacy and motivation to quit. Finally, higher baseline self-efficacy and motivation to quit were both associated with smaller decreases in self-efficacy and motivation to quit 4 weeks after app use.

The key finding from our analyses showed that the frequency of gamification use was associated with increased levels of self-efficacy and motivation to quit after app use compared with before app use. One possible reason for this could be that the frequency of gamification use has an effect on the overall user engagement with the app, which in turn influences the self-efficacy and motivation to quit levels. Some studies in the existing literature have found positive effects of gamification on user engagement. For example, Othman et al [45] found that gamification had a positive impact on user engagement with Play4fit, a fitness smartphone app. Similarly, Looyestyn et al [46] found that gamification was effective in increasing engagement levels with app-based programs. Therefore, higher overall app engagement as a result of gamification could have increased smokers’ confidence in their ability to quit and the level of motivation to quit. Moreover, as higher engagement has been found to be positively associated with intervention effectiveness [47,48], it is possible that apps with gamification features that influence the overall engagement levels are associated with better cessation outcomes than those without gamification features.

Although not explicitly investigated in our study, it is also possible that the frequency of gamification use had an effect on user enjoyment, which in turn affected the motivation to quit and self-efficacy levels. Higher levels of user engagement could intrinsically influence motivation levels, as the use of the app could be rewarding or enjoyable for the user regardless of the final outcome. The theory of flow suggests that people can experience the state of flow in which they are highly involved in an activity because it is so enjoyable that they would engage in it even at a cost [49]. Research shows that gamification elements can enhance the level of enjoyment experienced, leading to higher levels of motivation [49]. Another possible theory-based explanation for why the frequency of gamification use was found to be associated with increased self-efficacy levels could be that gamification may influence a user’s competence and confidence. Certain gamification features such as providing immediate feedback on performance, incremental levels, and providing badges of achievement could have provided a low risk way to attempt a task while also increasing confidence levels that their set goals are attainable [50]. According to the self-determination theory, the fulfillment of 3 types of psychological needs (autonomy, competence, and relatedness) can foster motivation [51]. By providing immediate feedback on performance through game elements such as badges, level advancements, and progress tracking, gamification may help fulfill competence needs and enhance self-efficacy.

On the other hand, elements such as the sharing feature could help support and enhance the feeling of relatedness and in turn boost motivation levels.

The association between perceived frequency of use of gamification features and increases in motivation to quit and self-efficacy can have important implications for the use of gamification and game design principles in nongame contexts such as health behavior change. We found progress tracking to be the most frequently used gamification feature after 4 weeks of app use. According to a review of smoking cessation mobile apps, this feature was found to be most commonly integrated into apps by app developers [52]. However, we also found that one of the gamification features that users interacted with frequently ( unlocking levels or completing stages) was also the feature that was adopted by only 20% of the smoking cessation apps investigated in the review. It could be valuable for app developers to investigate the impact of such gamification features as they are not often integrated into mobile apps but could have the potential to improve user engagement and thereby self-efficacy and motivation to quit. This also highlights the importance and need for collaboration between mobile app developers, researchers, and behavior change specialists to create interventions that can effectively target and influence vital cognitive factors via strategies such as gamification.

Our study also found some indications that the average perceived usefulness of gamification was associated with increased levels of self-efficacy and motivation to quit after 4 weeks of app use compared with baseline. This finding is in accordance with previous studies that have explored the impact of gamification on motivation to quit. For example, Pløhn and Aalberg [26] found that participants who managed to quit smoking after using a gamified app-based cessation program reported the effectiveness of gamification as a motivational factor [26]. Similarly, a study of 16 participants found that individuals who engaged in a gamified cessation intervention had higher levels of motivation than those who engaged with a nongamified cessation intervention [27]. Our findings, supported by other studies, highlight the value of further investigating the usefulness of specific gamification features to better design mHealth solutions geared toward facilitating health behavior change.

In addition to our findings on gamification, a general finding of our analyses was the increase in self-efficacy between baseline and 4 weeks after app use. This implies that participants experienced increased levels of confidence to refrain from smoking not only when faced with both internal stimuli such as cravings and emotions but also when faced with external stimuli such as being surrounded by other smokers or social situations that trigger smoking cravings. Likewise, the increase in motivation to quit between baseline and end-study suggests that participants experienced higher determination to quit and placed greater importance in successfully quitting on the current quit attempt. The association between high self-efficacy and motivation to quit with better cessation outcomes has been established in a large number of previous studies [6-9]. Although we did not assess quit outcomes in our study, the evidence that increased self-efficacy and motivation to quit can lead to better outcomes supports the findings of previous studies.
quitting rates is an encouraging finding for gamified smoking cessation apps. Such apps could be considered as possible cessation interventions available to smokers seeking to quit. Increased use of mobile apps for smoking cessation could also have wide-reaching consequences for alleviating health inequalities, as mHealth solutions are able to reach a large number of people at low cost [15].

It is important to note that the majority of increases in both self-efficacy and motivation to quit are evident during the first 2 weeks of app use. This could imply that the gamified mobile apps have a saturated effect after an initial period of using the app, after which they help participants maintain their self-efficacy and motivation levels. Past research has found that an increase in self-efficacy during the course of an intervention can lead to greater likelihood of long-term success [53]. Another study showed that participants who experienced an increase in self-efficacy during the first 2 weeks of a 12-week smoking cessation intervention were significantly more likely to stay quit after treatment [54]. The study also sheds light on the importance of promoting a smoker’s early sense of confidence in their ability to quit to increase the odds of successfully quitting long after the intervention is completed [54]. These findings could have possible implications for future smoking cessation interventions to adopt strategies to raise self-efficacy and motivation levels over the course of the intervention, especially early on.

Finally, our analyses also showed that having higher education, baseline self-efficacy, and motivation to quit were associated with smaller improvements in self-efficacy and motivation to quit. This suggests that the gamified mobile apps in our study have a greater benefit for individuals with lower levels of confidence in their ability to quit, individuals with lower determination to quit, and individuals with lower education levels or individuals with lower socioeconomic status. As socioeconomic differences are present in both smoking prevalence and successful cessation, this finding could be used to inform future interventions to help disadvantaged groups and thereby reduce inequalities.

Limitations

By examining the impact of gamified smoking cessation mobile apps quantitatively, we attempt to address a gap in the existing literature. However, to do so, we developed a questionnaire to quantitatively assess gamification that requires participant self-report. Self-reporting may have led to different or inaccurate perceptions, particularly when answering questions regarding frequency of use. Moreover, the developed questionnaire has not yet been scientifically validated. Future research could test the validity and reliability of the questionnaire developed to assess gamification more rigorously. Another drawback of our research was that the majority of participants reported having a low to moderate dependence on nicotine. It could be that the findings differed among individuals with high nicotine dependence. Therefore, future research could explore the differences between the various types of smokers. Similarly, participants with mental health conditions were not eligible to participate in the study, and it could be that the findings are not generalizable to all members of the population. Finally, our study comprised motivated volunteers, which could subject the findings to volunteer bias.

To address the natural limitations of this study design, future research could consider running randomized controlled trials with 2 smoking cessation apps that are as similar as possible, differing only in the number of gamification elements or, more importantly, the type of gamification elements to robustly test the impact of gamification. Our study was underpowered to investigate the impact of individual game elements; therefore, we were unable to explore the effects of and differences between game elements. Future studies could try to isolate and test individual game elements within behavior change interventions, as not all gamification elements may have the same impact or function in the same way. It could be that certain gamification elements interact with other elements or with individual dispositions, situational circumstances, and the characteristics of particular target activities differently than others [20]. Consequently, it is vital for future research to focus on theory-driven studies that investigate how individual gamification elements work.

Conclusions

In conclusion, our research found that more frequent engagement with gamification features in smoking cessation apps was associated with higher self-efficacy and motivation to quit. The findings of this study provide a good platform for further investigation into the role of gamification in improving important cognitive factors essential for the quitting process of smokers. Future studies should continue to explore the impact and usefulness of gamification in the context of mHealth. On the basis of our findings and existing literature, we recommend that mobile app developers collaborate with behavior change specialists to develop more tailored, evidence-based, and theory-driven interventions. At the same time, app developers should be encouraged to work together with scientists to explore and test strategies, such as gamification, that could target vital psychological components of behavior change while possibly improving engagement with the app.

Acknowledgments

Ethical approval was obtained from the Joint Research Imperial College London Research Ethics Committee (ICREC) before the beginning of the study (ICREC reference 19IC5158). This research did not receive a grant or funding from any agencies that are public, commercial, or within the not-for-profit sector. Quit Genius and Kwit provided free access to the study participants but had no other financial or material input.
Authors' Contributions

The 3 authors (NBR, NM, and FTF) jointly developed and designed the study. NBR handled day-to-day activities to manage the study and therefore conducted data collection. The statistical analyses presented in this paper were performed by NBR with assistance and guidance from NM and FTF. All authors reviewed the manuscript and approved the final version.

Conflicts of Interest

None declared.

Multimedia Appendix 1
Study participant flowchart.
[DOCX File, 46 KB - games_v9i2e27290_app1.docx ]

Multimedia Appendix 2
Screenshots of Quit Genius and Kwit.
[DOCX File, 646 KB - games_v9i2e27290_app2.docx ]

Multimedia Appendix 3
Gamification features and tactics by Cugelman embedded in the Kwit and Quit Genius apps.
[DOCX File, 13 KB - games_v9i2e27290_app3.docx ]

Multimedia Appendix 4
The t tests statistically examining the mean differences in self-efficacy and motivation to quit scores between study time points (n=116).
[DOCX File, 13 KB - games_v9i2e27290_app4.docx ]

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10. Motivation to Stop Smoking. NHS Center for Smoking Cessation and Training. URL: https://www.ncsct.co.uk/usr/pub/Motivation%20to%20stop%20smoking.pdf [accessed 2018-01-07]


Abbreviations

CBT: cognitive behavioral therapy
ICREC: Imperial College London Research Ethics Committee
mHealth: mobile health
PID: participant identification number
Integration of Motor Learning Principles Into Virtual Reality Interventions for Individuals With Cerebral Palsy: Systematic Review

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Abstract

Background: Increasing evidence supports the use of virtual reality systems to improve upper limb motor functions in individuals with cerebral palsy. While virtual reality offers the possibility to include key components to promote motor learning, it remains unclear if and how motor learning principles are incorporated into the development of rehabilitation interventions using virtual reality.

Objective: The objective of this study was to determine the extent to which motor learning principles are integrated into virtual reality interventions targeting upper limb function in individuals with cerebral palsy.

Methods: A systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The search was performed in 10 databases using a combination of keywords related to cerebral palsy, virtual reality, video games, and rehabilitation. Studies were divided into 2 categories: commercial video game platforms and devices and custom virtual reality systems. Study quality was assessed using the modified Downs and Black checklist.

Results: The initial search yielded 1497 publications. A total of 26 studies from 30 publications were included, with most studies classified as “fair” according to the modified Downs and Black checklist. The majority of studies provided enhanced feedback and variable practice and used functionally relevant and motivating virtual tasks. The dosage varied greatly (total training time ranged from 300 to 3360 minutes), with only 6 studies reporting the number of movement repetitions per session. The difficulty progression and the assessment of skills retention and transfer were poorly incorporated, especially for the commercial video games.

Conclusions: Motor learning principles should be better integrated into the development of future virtual reality systems for optimal upper limb motor recovery in individuals with cerebral palsy.

Trial Registration: PROSPERO International Prospective Register of Systematic Reviews CRD42020151982; https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020151982

(JMIR Serious Games 2021;9(2):e23822) doi:10.2196/23822
KEYWORDS

virtual rehabilitation; upper limb; brain damage; feedback; active video games; learning

Introduction

Cerebral palsy (CP) is the most common neuromotor disorder in children, with a prevalence ranging from 1.5 to 2.5 per 1000 births [1-3], that continues throughout adulthood. It is defined as “a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain” [4]. Due to structural brain abnormalities, individuals with CP have a wide range of sensorimotor impairments, including muscle tone disorders [5], sensory deficits [6-8], and deficits in interjoint coordination [9], motor execution, and planning [10,11]. These impairments ultimately lead to altered upper limb function. Due to the important contribution of the arms and hands in daily activities, deficits in upper limb functions ultimately may result in a poorer quality of life [12].

To improve both motor function and quality of life in individuals with CP, moderate to strong evidence supports motor learning-based approaches in rehabilitation [13,14]. Motor learning is defined as a set of processes based on principles of neuroplasticity associated with practice or experience that lead to relatively permanent motor changes [15,16]. The brain’s inherent ability to organize itself and to form new connections between neurons can be exploited with therapeutic rehabilitation approaches based on motor learning principles [17,18]. Key components of motor learning–based approaches include but are not limited to (1) intensive rehabilitation interventions involving a high number of task repetitions, (2) progressive incremental increases in task difficulty, and (3) salient interventions to enhance motivation and engagement in therapy [15,19]. The provision of extrinsic feedback on either the movement quality or the motor performance can also promote motor learning [20]. Extrinsic feedback can compensate for reduced availability and/or processing ability of intrinsic feedback in individuals with CP. However, provision of extrinsic feedback is often not individualized to the motor abilities of each individual nor standardized [20]. Additional challenges to incorporating motor learning principles in clinical practice include (1) accountability for the heterogeneity and severity of the sensorimotor impairments observed in CP, (2) personalization of interventions based on the individual’s needs or goals, and (3) delivery of exercises that are both challenging and enjoyable [21].

Use of technology has helped to address some of the aforementioned challenges with rehabilitation interventions. Technology-based interventions including virtual reality and active video games have gained popularity in rehabilitation, with many systems designed to encourage upper limb function [22-24]. Virtual rehabilitation refers to interventions that are built on virtual reality platforms to meet rehabilitation goals. It encompasses a continuum of technologies of different types and technical complexities ranging from fully immersive 3D virtual reality viewed using commercially available head-mounted displays (eg, Oculus Rift; Facebook Technologies, LLC) to active video games or exergames (eg, commercial video games used for rehabilitation purposes or active video games primarily used for physical activity) [25]. Rehabilitation using virtual reality–based platforms offers the possibility to deliver high-intensity training in a multimodal training environment [26]. Virtual reality interventions also provide a unique opportunity to customize and standardize the levels of task difficulty by modifying the spatial and temporal constraints and the cognitive challenge. Feedback provision on the individual abilities and delivery modes can be easily manipulated. The task outcome and quality can be automatically recorded, which is useful to both clinicians and researchers [27].

Virtual reality has been shown to be safe and ecologically valid for the rehabilitation of individuals with CP [28-30]. The novelty of virtual reality technology and the interactive and engaging gaming characteristics are key components that provide a joyful training environment to sustain and enhance motivation to treatment [31,32]. Therefore, the attributes of virtual environments such as motivation, repetitive practice, and enhanced feedback make them an ideal modality to facilitate the incorporation of motor learning principles into the treatment of individuals with CP.

Several systematic reviews and one meta-analysis investigated the impact of virtual reality interventions on upper limb motor recovery in children and adolescents with CP [13,22,27,33-35]. Their results suggest, to an extent, that virtual reality can be effective and motivating for children with CP. Another literature review specifically looked at the effectiveness of virtual reality on motor learning in children with CP [36]. The results support virtual reality interventions to improve motor learning and encourage skill transfer to real-life situations. A current knowledge gap in the literature relates to which exact motor learning principles are incorporated into virtual reality–based platforms used for upper limb rehabilitation in individuals with CP (children, adolescents, and adults). The limited incorporation of key motor learning principles in therapy (eg, treatment intensity and specificity, feedback provision and delivery, and difficulty progression) could explain differences observed between studies and also limit the potential for motor learning in individuals with CP. This systematic review aims to identify the extent to which motor learning principles are integrated into virtual reality interventions targeting upper limb function in individuals with CP. The incorporation of motor learning principles will be identified for commercial video game platforms and devices and custom virtual reality systems for rehabilitation to help guide clinical decision making.

Methods

Protocol and Registration

This systematic review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, and results are reported using the PRISMA checklist [37]. The protocol for this systematic review was registered on PROSPERO (CRD42020151982).
Eligibility Criteria
We included publications related to the effectiveness of virtual reality interventions on upper limb sensorimotor function at the levels of body function/structure or activity limitations according to the International Classification of Functioning, Disability and Health in individuals with CP. We only included peer-reviewed publications in English or French in which the majority of the sample included individuals with CP (children or adults). We excluded publications that (1) used solely qualitative methodologies (eg, focus groups and interviews), (2) focused on the development of the virtual reality intervention, (3) used virtual reality as an assessment tool, or (4) were reviews, meta-analyses, or commentaries.

Information Sources
The following electronic databases were searched on August 22, 2019, and updated on July 5, 2020, using a combination of keywords related to CP, rehabilitation, video games, and virtual reality: MEDLINE, Embase, CINAHL, Web of Science, Google Scholar, OTseeker, Physiotherapy Evidence Database, IEEE Xplore, Scopus, and Cochrane Library, and the Cochrane Central Register of Controlled Trials. The reference lists of articles of interest were also searched for additional references. The search strategy was developed for the MEDLINE database and adapted for other databases. Various combinations of keywords and Medical Subject Headings (MeSH) or Embase subject headings (Emtree) related to virtual reality or video games, rehabilitation, and CP were used (see Multimedia Appendix 1 for the detailed search strategy). No time limit regarding the date of publication was applied to the search strategy.

Search and Study Selection
The search strategy was executed by one researcher (MD), and all publications from each database were extracted using citation management software (Endnote X9; Clarivate). Any duplications were removed. Titles and abstracts were screened independently by two researchers (MD and KF) based on the inclusion and exclusion criteria. For all potential eligible studies, full texts were retrieved, and eligibility was assessed by the same two researchers. Any conflict was resolved by discussion.

Data Collection Process and Data Items
For all publications meeting the inclusion criteria, one researcher (MD) extracted the following information into an Excel (Microsoft Inc) spreadsheet: author/date, study design, participants, sample size, virtual reality system, delivery method, number of movement repetitions, intensity, task specificity, difficulty progression, type of practice, type of feedback, feedback delivery schedule, motivation, motor recovery outcome measures, changes in upper limb motor function (body function/structure or activity limitation levels), assessment of skills retention, and assessment of transfer of skills. Another researcher (KF) validated the data extraction by reading all included publications and confirming that the data extracted were accurate and complete. Publications presenting the results from the same group of participants were considered a single study and the results were extracted together. Since there is a lack of clear definition of motor learning principles in CP, we used the definition and key descriptors of Maier et al [38] for dosage, type of practice, feedback provision, and task specificity. For treatment intensity and duration, the number of movement repetitions was extracted and the number of minutes of treatment was computed using the treatment duration, frequency, and number of weeks of the intervention. Data were analyzed separately for commercial video game platforms and devices and custom virtual reality systems for rehabilitation. Commercial video game platforms and devices included salon game consoles and commercially available applications on a tablet. Custom virtual reality systems for rehabilitation included commercially available or custom virtual reality software programmed for rehabilitation purposes. Studies using special hardware (eg, instrumented gloves or robotic devices) or repurposed commercial gaming hardware (eg, the Microsoft Kinect camera) were included in the custom virtual reality software category.

Risk of Bias in Individual Studies
Two authors (SKS and MTR) analyzed the quality of each study, and conflicts were resolved by discussion. The 27-item modified version [39] of the original Downs and Black checklist [40] helped assess the quality of the included randomized and nonrandomized studies. The overall quality of the research was scored out of 28 based on the following criteria: reporting, internal validity, power, and external validity. Scores on the modified Downs and Black checklist were classified as “excellent” (scores of 24-28), “good” (scores of 19-23), “fair” (scores of 14-18), or “poor” (scores ≤13) [41]. The Downs and Black checklist was chosen over other measures, such as the Effective Public Health Practice Project [42], because it considers sample size in the total score calculation and enables studies to be quantitatively classified into different categories based on the total score. The Downs and Black checklist has previously been used in studies involving virtual reality interventions for upper limb rehabilitation [43].

Results
The database search yielded 1497 publications, and 749 publications were screened for eligibility after duplicates were removed. After full-text review, 26 studies from 30 publications were included (see Figure 1 for flow diagram and reasons for exclusion).
Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow chart of study selection.

Quality Assessment

The quality ratings of the publications based on the Downs and Black checklist are shown in Table 1. Only 17 studies were rated because the remaining studies were either case studies or short papers. Of the 17 studies, 2 were rated as good, 14 as fair, and 1 as poor.

Table 1. Quality assessment of the reviewed studies based on the 27-item modified version [39] of the Downs and Black checklist [40].

<table>
<thead>
<tr>
<th>First author and publication year</th>
<th>Downs and Black score/28</th>
<th>Quality of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avcil et al, 2020 [44]</td>
<td>21</td>
<td>Good</td>
</tr>
<tr>
<td>Bedair et al, 2016 [45]</td>
<td>16</td>
<td>Fair</td>
</tr>
<tr>
<td>Chen et al, 2007 [46]</td>
<td>15</td>
<td>Fair</td>
</tr>
<tr>
<td>Sharan et al, 2012 [47]</td>
<td>13</td>
<td>Fair</td>
</tr>
<tr>
<td>El-Shamy, 2018 [48]</td>
<td>16</td>
<td>Fair</td>
</tr>
<tr>
<td>Fluet et al, 2009 [49]</td>
<td>16</td>
<td>Fair</td>
</tr>
<tr>
<td>Fluet et al, 2010 [50]</td>
<td>15</td>
<td>Fair</td>
</tr>
<tr>
<td>Hernández et al, 2018 [51]</td>
<td>17</td>
<td>Fair</td>
</tr>
<tr>
<td>Jannink et al, 2008 [52]</td>
<td>14</td>
<td>Fair</td>
</tr>
<tr>
<td>Kassee et al, 2017 [53]</td>
<td>17</td>
<td>Fair</td>
</tr>
<tr>
<td>Odle et al, 2009 [54]</td>
<td>14</td>
<td>Fair</td>
</tr>
<tr>
<td>Rostami et al, 2012 [55]</td>
<td>18</td>
<td>Fair</td>
</tr>
<tr>
<td>Sahin et al, 2020 [56]</td>
<td>19</td>
<td>Good</td>
</tr>
<tr>
<td>Sandlund et al, 2014 [57]</td>
<td>13</td>
<td>Fair</td>
</tr>
<tr>
<td>Turconi et al, 2016 [58]</td>
<td>18</td>
<td>Fair</td>
</tr>
<tr>
<td>Weightman et al, 2011 [59]</td>
<td>12</td>
<td>Poor</td>
</tr>
<tr>
<td>Winkels et al, 2013 [60]</td>
<td>13</td>
<td>Fair</td>
</tr>
</tbody>
</table>
Characteristics of the Virtual Reality Systems

Of the 26 studies, 9 (35%) used commercial video game platforms and devices, such as the Nintendo Wii, the Sony PlayStation 2 or 3, Xbox consoles (Microsoft Corporation), or commercial applications [44,45,47,52,53,58,60-62]. Custom virtual reality systems for rehabilitation were used in 17 studies (65% [46,48,50,51,54-56,59,63-71]). Commercially available virtual reality systems designed for rehabilitation purposes were used in 5 studies (19%): ArmeeoSpring (Hocoma) combined with virtual games [48]; E-Link Evaluation and Exercise System (Biometrics Ltd) [55]; IREX (GestureTek Health) [66]; Timocco [64]; and YouGrabber (YouRehab) [67]. Seven studies (27%) used custom-based games combined with commercially available accessories (ie, Microsoft Kinect camera [56,68,72], webcam [54], force-feedback motion controller [51], or instrumented gloves [69,70]). Custom virtual reality systems designed for rehabilitation research purposes were used in 4 studies (15%) [49,50,59,65,71]. Display media used to view the virtual environments included stereoscopic glasses to enable 3D media display view [49,50,71] and television or computer monitors to view 2D virtual environments with various 3D rendering features (ie, shadow, drop lines, etc). Virtual environments ranged from a simple display of reaching targets in a 2D plane to a detailed replication of real-life environments, such as a tennis court or a kitchen. None of the studies used immersive virtual reality through a head-mounted display.

Study Characteristics

The study settings and targeted participants varied greatly. Sample sizes ranged from 1 to 30 participants in the intervention group, with 12 studies (46%) having a sample size of 5 participants or fewer. While our search strategy did not exclude studies conducted in adults with CP, none of the studies targeted participants over 18 years of age (see Figure 2 for detailed study characteristics). All studies targeted school-aged children (over 4 years of age) or adolescents. In 17 studies (65%), treatment was delivered in a laboratory setting [46,48,50,55,58,61,65-67,71] or a rehabilitation center [45,47,51,52,54,60,68]. In 6 studies (23%), the virtual reality–based intervention was delivered at home using either telerehabilitation technologies (ie, videoconferencing and remote monitoring [64,69,70]) or a prescribed exercise program [53,57,59].

Figure 2. Characteristics of the reviewed studies according to (A) study design, (B) participants’ age groups (preschoolers: aged 0-4 years; children: aged 4-12 years; teenagers: aged 13-18 years), (C) virtual reality (VR) system type, and (D) delivery environment. RCT: randomized controlled trial.

Motor Learning Principles in Studies Using Commercial Video Game Platforms and Devices

Among the 9 studies (35%) using commercial video game platforms and devices, the length of sessions varied from 20 to 60 minutes (Figure 3 and Multimedia Appendix 1). Frequency ranged from 2 to 5 sessions per week for 3 to 12 weeks, with a total treatment time ranging from 360 to 1440 minutes. Only Kassee et al [53] discussed the number of movement repetitions, suggesting that the number of movement repetitions in the virtual reality group was comparable with that in the resistance training group (144 repetitions per session). Jannink et al [52] indicated that the intensity level was moderate but did not define how intensity was measured in their study. Task-specific training, in which movements were goal-oriented or relevant for activities of daily living, was used in all 9 studies and the majority simulated competitive sports. Examples of task-specific training included playing various sports (eg, tennis, bowling, sword fighting), controlling a moving car, piloting a spaceship, and catching falling balls. Variable practice was delivered in all studies using commercial video game platforms and devices.
by using frequent changes of tasks. However, none of the studies clearly specified the type of practice offered with the intervention. None of the publications reported whether the games were adapted to match the participant’s capacity and, if so, how they were adapted and how the difficulty levels were changed.

Figure 3. Percentage of commercial video game platforms and devices and custom virtual reality systems for rehabilitation integrating the principles of motor learning.

Visual and auditory feedback were provided in all studies as a display of total score and/or reward sounds. Additional haptic feedback (vibration) was offered by a motion controller held in the most-affected hand in 2 studies [44,53]. All studies delivered continuous feedback. For virtual interventions, an example of continuous feedback is the provision of knowledge of results after each trial, such as the rate of success or total score. Motivation with the intervention was assessed in 6 studies (23%) using questionnaires (eg, a visual analog scale for motivation and a participant and parent feedback questionnaire), therapists’
observations, or semistructured interviews. High motivation to practice in a virtual environment was reported [47,52,53,58,60,62]. However, Sandlund et al [57] noted that children’s interest in gaming faded somewhat over time. Winkels et al [60] observed that motivation varied between games and children. In 2 studies, greater motivation was observed in the Wii training group than in a control group [47,53]. Retention of motor skills was assessed in only 2 studies [53,61]; the results of both studies suggested that motor skills were retained 4 weeks after the intervention. Transfer of skills was only assessed in 1 study, with the skills shown to be transferred to a similar reaching task [57].

Motor Learning Principles in Studies Using Custom Virtual Reality Systems for Rehabilitation

In all 17 studies (65%) using custom virtual reality systems for rehabilitation, the treatment frequency and intervention dosage were clearly reported, with the total training time ranging from 300 to 3360 minutes. The number of movement repetitions was reported in only 5 studies (range of 45 to 550 repetitions per session) [46,50,51,59,72]. Nine studies (35%) delivered task-specific training with functionally relevant tasks [46,48-50,56,64,66-68,71]. Thirteen studies (50%) delivered variable practice, with 4 studies (15%) also delivering massed practice (eg, minimal time between sessions and large number of movement repetitions to a single target) [46,49-51,59] and 1 study (4%) using random practice (ie, randomized tasks to maintain patients’ interest) [70]. Two studies (8%) delivered constant practice [64,65], while the remaining studies did not specify the type of practice used. Task difficulty was increasingly progressed in 12 studies [46,48,50,51,55,59,65,67-71] by different methods, including a modification of the ranges of motion required to accomplish the task, an increase or decrease in the amount of assistive and/or resistive force, and a change in the speed, accuracy, or target characteristics. Difficulty levels were progressed by the system using an algorithm, based on the judgment of a therapist according to task success, according to difficulties reported by the participants, or based on preset difficulty levels (eg, easy, medium, hard).

Multisensory feedback that combined visual and auditory and/or haptic feedback was offered in 11 studies (42%) [46,48-51,55,59,63,64,70,71,73]. Six studies (23%) provided only visual feedback [54,56,64-66,68]. Feedback was delivered continuously in all studies, but 1 study did not report on feedback frequency [51]. Motivation was assessed in 6 studies (23%) using subjective assessment or semistructured interviews [46,50,51,64,69,71]. The results suggested that the virtual environments were motivating, but Chen et al [46] and Hernández et al [51] reported that motivation levels were highly variable from one child to another, ranging from low to high. Retention of motor skills was assessed in only 4 studies [46,55,65,66]; in 3 of the 4 studies, the motor skills gained by the virtual reality intervention were maintained or improved at 1 to 3 months [46,55,66]. Three studies assessed the transfer of skills [51,59,66]. Hernández et al [51] reported that all children made significant progress on their self-selected goals, which largely targeted activities of daily living and leisure. In another study [66], 66% of the children showed a transfer of skills to a similar reach-to-grasp task for all kinematic variables. Weightman et al [59] noticed improvements in activities of daily living not directly targeted by the intervention.

Discussion

Principal Findings

The objective of this systematic review was to examine the extent to which motor learning principles are integrated into virtual reality interventions in individuals with CP. A total of 26 studies met the inclusion criteria, of which 9 used commercial video game platforms and devices and 17 developed custom virtual reality systems for rehabilitation. Overall, the studies were considered fair based on the Downs and Black checklist, given that the majority of them were small pilot or proof-of-concept studies. Nonetheless, the novelty of this review is that virtual reality is well-suited to incorporate motor learning principles into rehabilitation interventions targeted at children and adolescents with CP. Proper integration of motor learning principles is important, as demonstrated by the fact that the most effective therapies (ie, constraint-induced movement therapy and bimanual therapy) for improving upper limb motor functions are themselves based on motor learning principles and principles of neuroplasticity [13,74,75]. Enhanced feedback provision, variable practice, task specificity, and motivation were the motor learning principles most frequently adopted in virtual reality interventions for children and adolescents with CP. Dosage varied greatly from one study to another with only a few studies reporting the number of movement repetitions per session. The application of some principles (ie, difficulty progression and assessment of skills retention and transfer) were poorly integrated, especially in commercial video game platforms and devices.

It is widely accepted that rehabilitation interventions should be delivered at a high intensity (dose, frequency, and duration of training) to engage neuroplastic mechanisms [15]. Unfortunately, our results showed that many of the reviewed studies did not provide sufficient information on the number of repetitions performed per session. Although intensive and repetitive practice is important, repetitive motor activity alone is insufficient to induce experience-dependent plasticity [76]. Virtual reality enables the possibility to deliver high-intensity practice of engaging and meaningful tasks along with relevant feedback. This promotes a problem-solving approach known to be useful for enhanced rehabilitation outcomes. Additionally, a close collaboration between game developers, academia, and clinicians in the development of both commercial and custom virtual reality systems would help identify the clinical needs and optimize virtual reality interventions for individuals with CP [77].

Extrinsic Feedback

In both the commercial and custom virtual reality systems, feedback provision was well integrated. Feedback plays a crucial role to enhance motor learning and motivation level [78,79]. All studies reported providing feedback at a continuous frequency, yet provision of continuous feedback is often not optimal for motor learning. Continuous feedback limits the opportunity for learning to occur through exploration and
increases the dependence of the user on the feedback to improve specific goals, thereby affecting the ability of learning to detect and correct errors [80]. While continuous feedback may increase skills acquisition, retention of improvements is rarely sustained over time beyond the cue that prompted them (ie, feedback). Alternatively, provision of faded feedback (ie, gradual decrease in feedback provision as the learner improves) or self-controlled feedback may encourage the participant to explore and internalize new movement patterns, thus increasing the retention of these newly acquired skills [81,82]. Based on the limited evidence on the feedback modality that should be prioritized, a combination of multimodal feedback (ie, visual, auditory, and haptic) is proposed to be more effective for improving motor performance [80,83]. All studies using commercial video game platforms and devices implemented multimodal feedback. In contrast, approximately one-third of the studies using custom virtual reality systems delivered solely visual feedback. This could be because of the technical complexity required to program multimodal feedback and the lack of knowledge about which feedback modality should be provided in rehabilitation settings. Feedback should be implemented in a structured manner considering the individual capacities and errors made and thus allow the progression of difficulty throughout the intervention period. The use of theoretical frameworks, such as the framework developed by Schüll et al [84], can help designers and researchers to identify the beneficial components of virtual reality systems for specific treatment goals.

**Progression of Difficulty**

Constant progression of difficulty promotes motor learning because an individual’s abilities are considered within the conditions of a specific learning experience. According to the Challenge Point Framework [85], learning occurs through active problem solving. Errors committed during motor learning are necessary to both improve movement behavior and provoke neuroplasticity [86]. The majority of custom virtual reality systems for rehabilitation successfully implemented this concept. Unfortunately, all 9 studies using commercial video game platforms and devices did not report on the progression of difficulty, which does not enable assessment of whether the participants in these studies were appropriately challenged. This is somewhat surprising, since game developers generally integrate difficulty progression to maintain players’ enjoyment. Commercial video game platforms and devices can have limited therapeutic value for individuals with physical disabilities because they are designed for nondisabled populations [87]. Depending on the severity of the sensorimotor impairments, individuals with CP may not achieve the minimum threshold to progress through the difficulty levels in a given game. The concept of progression of difficulty is nonnegligible, as it may have a negative impact if a task is deemed too difficult. Thus, the strong association between challenge and motivation highlights the importance of delivering interventions at an appropriate difficulty level.

**Motivation**

Motivation is a critical element of rehabilitation, especially in the pediatric population [88,89]. A lack of motivation both increases activity limitations and decreases the child’s participation, thus hindering adherence to treatment [88]. Higher levels of motivation help lead an individual toward satisfying their specific needs and achieving goals in a persistent manner [90]. Given that most commercial games have high production value and include gamification elements to promote motivation and volition [91], most of the studies using commercial video game platforms and devices reported a high level of motivation. However, it is also possible that while commercial video games may be perceived as motivating and fun, they might still be too difficult for participants with CP. Driving elements of motivation include appropriately challenging tasks, game variability, setting realistic goals, and aspects of competition such as a reward system [92]. Unfortunately, these elements were often not incorporated into custom virtual reality systems for rehabilitation. Reasons contributing to these findings could include a lack of financial resources available in the development of a game and/or the lack of collaboration between game developers, clinicians, and end users. Future studies must comprehensively assess and report motivation levels and whether or not they were sustained in the long term. Moreover, strategies used to drive motivation should also be reported to completely understand the utility of such strategies.

**Retention and Transfer of Skills**

Two of the most important principles of motor learning pertain to how much the improvements are retained over an extended period and how much of the newly acquired skill can be transferred to performance of a similar task [93,94]. The majority of the studies reviewed, regardless of the type of virtual reality used, did not examine these principles in depth. A few studies, however, referenced the potential to retain the newly acquired upper limb skills [46,55,61,66], as well as the possibility to transfer motor skills to real-life activities [51,57,66,73]. Virtual reality is well suited to address important factors that potentially encourage retention and transfer of skills, such as high enjoyment level, physical fidelity of the practiced movement, and high repetitions. Thus, retention is an important factor that must be addressed in future studies.

**Type of Practice**

Relatively few details were provided regarding the practice conditions used for studies with the commercial video game platforms and devices. For the custom virtual reality systems, 4 studies reported using massed practice. The beneficial impact of massed or distributed practice on learning is not clear and is likely related to contextual factors such as the nature (discreet vs continuous) and the difficulty of the task or the expertise of the participants. A pilot study conducted in healthy participants that compared massed practice with distributed practice in a virtual reality setting did not report any significant difference between these 2 types of practice [95]. Thirteen studies reported using variable practice, while only 1 study reported using random practice. Both variable and random practice tend to negatively affect short-term performance but often have a positive long-term impact on skill retention and transfer [96]. Variable and random practice are notably more cognitively engaging [97], more challenging, and improve generalization and adaptability, as observed when performing a novel variation of a task [85]. Our results show that many interventions do not
take full advantage of increasing variability within trials to optimize skill retention and transfer. The concept of variability was first introduced by Bernstein [98], who emphasized that the success of practice relies on the process of solving a problem repetitively. To this day, this concept remains relevant and should be considered when developing virtual reality interventions. Nonetheless, it should be noted that in some contexts, blocked and constant practice might be more suitable, notably in younger children or in difficult tasks [99-101]. Therefore, virtual reality software should be flexible enough to allow the clinician to adjust the variability within a block of trials in order to maximize motor learning.

**Limitations**

Overall, our interpretation of the results of these studies was limited by the available information provided in the publications. For example, inconsistent reporting of the type of feedback and delivery schedule hindered our ability to conclude whether feedback was provided in the form of knowledge of performance or knowledge of results [102]. In other words, our review was constrained by the level of detail in the studies’ methodology sections, which often mirrored the quality of the studies. Thus, no conclusion was drawn on the effectiveness of virtual reality in rehabilitation, as it was beyond the scope of this review.

**Conclusions**

This review demonstrates the current integration of select principles of motor learning into commercial video game platforms and devices and custom virtual reality systems designed for upper limb motor recovery. Overall, motor learning principles are not yet being fully integrated into virtual reality systems, especially into commercial video game platforms and devices, because the target audience is not individuals with disabilities. Custom virtual reality systems are better tailored to the needs of individuals with CP and provide an experience better adapted to the capacity of individuals in terms of difficulty. However, the custom virtual reality systems used in this review were not as engaging as commercial video game platforms and devices nor did they provide multimodal feedback. Nonetheless, designing an intervention using multimodal feedback may be feasible with the proper resources. The integration of motor learning principles into such a system would help maximize its efficiency and offer a cost-effective intervention to supplement standard treatments in the clinical setting. Future research should provide detailed methodology on the extent to which motor learning principles are integrated to help evaluate the efficacy of video game platforms and devices and virtual reality systems in improving upper limb function.

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**Authors’ Contributions**

All authors contributed to the writing of the manuscript and its critical revision. MD performed the search strategy, study selection, and data extraction and analysis, and drafted the manuscript. KF performed the study selection and verified the data extraction. SKS and MTF assessed the quality of the reviewed studies.

**Conflicts of Interest**

None declared.

Multimedia Appendix 1
Detailed search strategy.
[PDF File (Adobe PDF File), 184 KB - games_v9i2e23822_app1.pdf ]

**References**


Abbreviations

CP: cerebral palsy
MeSH: Medical Subject Headings
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
A Gamification Framework for Cognitive Assessment and Cognitive Training: Qualitative Study

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Abstract

Background: Cognitive tasks designed to measure or train cognition are often repetitive and presented in a monotonous manner, features that lead to participant boredom and disengagement. In this situation, participants do not put forth their best effort to do these tasks well. As a result, neuropsychologists cannot draw accurate conclusions about the data collected, and intervention effects are reduced. It is assumed that greater engagement and motivation will manifest as improved data quality. Gamification, the use of game elements in nongame settings, has been heralded as a potential mechanism for increasing participant engagement in cognitive tasks. Some studies have reported a positive effect of gamification on participant performance, although most studies have shown mixed results. One reason for these contrasting findings is that most studies have applied poor and heterogeneous design techniques to gamify cognitive tasks. Therefore, an appropriate gamification design framework is needed in these tasks.

Objective: This study aimed to propose a framework to guide the design of gamification in cognitive tasks.

Methods: We employed a design science research (DSR) approach to provide a framework for gamifying cognitive assessments and training by synthesizing current gamification design frameworks and gamification works in cognitive assessment and training, as well as incorporating field experiences. The prototypes of the framework were iteratively evaluated with 17 relevant experts.

Results: We proposed a framework consisting of 7 phases: (1) preparation; (2) knowing users; (3) exploring existing tools for assessing or training a targeted cognitive context and determining the suitability of game-up and mapping techniques; (4) ideation; (5) prototyping using the Objects, Mechanics, Dynamics, Emotions (OMDE) design guideline; (6) development; and (7) disseminating and monitoring.

Conclusions: We found that (1) an intermediate design framework is needed to gamify cognitive tasks, which means that game elements should be selected by considering current cognitive assessment or training context characteristics since game elements may impose an irrelevant cognitive load that, in turn, can jeopardize data quality; (2) in addition to developing a new gamified cognitive task from scratch, 2 gamification techniques are widely used (first, adding game elements to an existing cognitive task and second, mapping an existing game to a cognitive function or impairment to assess or train it); and (3) further research is required to investigate the interplay of cognitive processes and game mechanics.

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KEYWORDS
cognitive tasks; boredom; motivation; gamification; game elements; framework; process; gamification design; cognitive training; cognitive assessment
**Introduction**

**Background**

Statistics show that the cognitive assessment and training market will achieve a growth rate of 32.39% from 2018 to 2022, and gamification will be one of the key vendors operating in this market [1]. These statistics confirm another estimation that shows 1 out of 5 people will be over 60 years old in the next 40 years [2]. Minor and major neurocognitive disorders, which have prevalences of approximately 10%-20% and 5%-7%, respectively, are global health issues due to the aging population; according to the American Psychiatric Association Diagnostic and Statistical Manual of Mental Disorders, edition 5, minor and major neurocognitive disorders encompass mild cognitive impairment and dementia, respectively [3]. In minor neurocognitive disorders, cognitive abilities decline, but changes are not severe enough to significantly affect individuals’ activities of daily living (ADLs); 35% of individuals with a minor neurocognitive disorder progress to a major neurocognitive disorder within a 3-year period [4]. In this stage, individuals lose independence in their ADLs and require care and support from others. It is not only aging that causes cognitive impairments; they may also exist since childhood (such as attention deficit hyperactivity disorder [ADHD] and autism spectrum disorder) or because of different factors like alcohol or drug abuse [5-7].

Cognitive assessment and training play an essential role in preventing loss of autonomy and independence in ADLs [8]. Cognitive assessment is associated with evaluating individuals’ cognitive abilities (eg, working memory, attention, executive functions) [9]. Cognitive training refers to using cognitive tasks to maintain or improve a particular aspect of cognitive functioning [9]. There are cognitive tasks to assess or train cognitive functions. Cognitive tasks such as the Mini-Mental State Examination (MMSE) [10], Confusion Assessment Method (CAM) [11], and Montreal Cognitive Assessment (MoCA) [12] are widely used for cognitive assessment. There are also cognitive training companies that have developed cognitive training tasks such as Cogmed [13], Nintendo Brain Age [14], Lumosity [15], and Posit Science BrainHQ [16]. The prevailing approach in these companies for designing a training task is to convert lab-based and individualistic cognitive assessment tasks into a training task [17] (eg, Nintendo Brain Age includes several cognitive assessment tasks like the Stroop task [18]). Cognitive tasks are a vital tool for the assessment and training of cognitive impairments. However, participants often view them as monotonous and boring since they have a repetitive nature and are rigidly presented [8,9,19-23]. These features increase the frequency of insufficient efforts to perform these tasks, and consequently, the reliability of data collected decreases [9,19,23-26]. The typical process taken by cognitive specialists to perform a cognitive training program is shown in Figure 1.

![Figure 1](https://games.jmir.org/2021/2/e21900)  
Figure 1. The process of traditional cognitive training programs (the figure was drawn based on descriptions provided by Vourvopoulos et al [8]). ADLs: activities of daily living.

It is assumed that greater engagement and motivation will manifest as improved data quality in cognitive tasks [9,19-27]. Among the existing solutions, gamification, which is the process of adding game elements (eg, scoring system, leaderboard, badge) to nongame contexts (eg, education context, business context, cognitive tasks) [28], stands as one of the most influential and promising solutions to improve motivation in monotonous tasks [9]. A greater understanding of human motivation helps maintain users' encouragement to participate in cognitive tasks over time [17]. Motivation is multidimensional and falls on a continuum from intrinsic motivation to extrinsic motivation to amotivation (little to no motivation exists) [29]. Intrinsic motivation is regulated internally and refers to performing activities for their inherent satisfaction. Intrinsic motivation is required for long-term engagement and long-term changes. In contrast, extrinsic motivation (doing activities solely...
for their outcomes and rewards) is useful for short-term engagement and short-term changes and is also regulated externally [29,30]. Self-determination theory (SDT) [31] and Flow [32] theory are widely used to improve users’ participation and motivation. According to SDT [31], intrinsic motivation can be sustained by satisfying 3 psychological needs of relatedness (is experienced when individuals feel connected to others), autonomy (the need for freedom to make choices based on one’s volition during an activity), and competence (the need for challenge and feelings of self-efficacy). Flow refers to “the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it” [32]. Gamification can combine intrinsic motivation with extrinsic motivation to raise motivation and engagement [30]. Game elements such as badges, points, game levels, a leaderboard, and avatars lead to extrinsic motivation and are useful for capturing early user motivation [17]. Boendermaker et al [34], Lumsden et al [9], and Van de Weijer-Bergsma et al [35].

**Figure 2.** Examples of gamified cognitive tasks. A task was categorized as an assessment or training according to the self-prescription provided by the authors of the publication. The owl and apple pictures were used or adapted by [33] from openclipart [36] and 4vector [37] (online media repository of free graphics). ADHD: attention deficit hyperactivity disorder.

<table>
<thead>
<tr>
<th>Author_year</th>
<th>Cognitive task</th>
<th>Targeted cognitive function(s) or disorder(s)</th>
<th>Assessment or training</th>
<th>Short description</th>
<th>Corresponding pictures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craven and Groom, 2015 [33]</td>
<td>Go/No-Go</td>
<td>ADHD</td>
<td>Both</td>
<td>Focuses on gamifying the Go/No-Go task, which is a cognitive task used to assess the ability to inhibit a response. Participants must respond or withhold a reply depending on whether a Go or No-Go stimulus is presented. In the gamified version (awkward owls), a narrative is given for participants. They play a conservation volunteer’s who collects rare yellow owls (Go stimulus) for a wildlife survey and ignores brown owls (No-Go stimulus). After each response, depending on the displayed stimulus, the message “footloose” or “bouzi” is shown.</td>
<td><img src="image" alt="owls" /> <img src="image" alt="apple" /></td>
</tr>
<tr>
<td>Craven and Groom, 2015 [33]</td>
<td>Stop Signal Task (SST)</td>
<td>ADHD</td>
<td>Both</td>
<td>Here. SST was gamified, called wormy fruit. A sequence of fruits is presented. Fruits and wormy fruits are the Go and Stop signals, respectively. Eaten fruit and wormy fruit result from a response to the stimulus and missing the Stop, including clicking early before the Stop when the fruit is wormy.</td>
<td><img src="image" alt="owls" /> <img src="image" alt="apple" /></td>
</tr>
<tr>
<td>Boendermaker et al, 2015 [34]</td>
<td>Go/No-Go</td>
<td>Working memory</td>
<td>Training</td>
<td>To train alcohol bias. Go/No-Go was gamified in a game called cheese ninja. The game consists of a mouse ninja that walks through a hallway and passes posters of the same beverages used in the regular task. A good (cheese) or bad (rat) cue is shown in front of the posters. The player should collect as many useful objects as possible while ignoring the bad ones.</td>
<td>Not provided</td>
</tr>
<tr>
<td>Lumsden et al. 2016 [9]</td>
<td>Go/No-Go</td>
<td>Response inhibition</td>
<td>Assessment</td>
<td>Two gamified versions of the Go/No-Go task were developed to assess response inhibition ability. The standard task contains 20 everyday objects: 15 green (go stimulus) and 5 red (No-go stimulus) objects. The first gamified variant was identical to the standard task except that a point system based on that of Miranda and Palmer [27] was incorporated. In the second gamified version, the original task was themed as a cowboy shootout game in which participants are the sheriff of a town and a group of criminals hole up in a saloon and take hostages. During the game, a cartoon saloon appears, and stimuli are shown in the doorway. The participants have to shoot cowboys as Go targets and hold their response when they see innocent civilians as No-go targets. By responding to the displayed No-go stimulus, a blood splat overlay on it for the remainder of the game time.</td>
<td><img src="image" alt="cowboy" /> <img src="image" alt="saloon" /></td>
</tr>
<tr>
<td>Van de Weijer-Bergsma et al, 2014 [35]</td>
<td>Working memory task</td>
<td>Visual-spatial working memory, updating, shifting, and inhibition skills</td>
<td>Assessment</td>
<td>Foresee on gamifying a working memory task for children, named the lion game. A 4x4 matrix containing 16 bushes is presented. In different locations for 2000 ms, 8 lions of different colors are continuously shown. Participants should remember the last place where a lion of a specific color (e.g., Blue) appears using the mouse button to click on that location after the sequence ends. The game consists of 5 levels, in which working memory capacity is manipulated by changing lions’ colors and locations.</td>
<td><img src="image" alt="lion" /> <img src="image" alt="bushes" /></td>
</tr>
</tbody>
</table>

**Challenges With Designing Gamification for Cognitive Assessment or Training**

Despite the growing trend towards using gamification in cognitive tasks, its impacts on participant engagement and data quality are not stable. Studies have [20-22,27,38-40] stated that gamification has a positive effect on users’ engagement as well as data quality. However, other studies [19,24,26,34] have reported that no effects were observed on users’ performance by adding game elements, but they perceived the gamified task as funnier and more challenging than the nongamified version. In addition, other studies [19,27] showed that gamification worsened data quality but had positive effects on engagement. The gamification applied by Birk et al [23] not only did not have a positive impact on data quality and engagement but also worsened them [19]. These mixed findings are potentially due to 4 main reasons: (1) Most gamified cognitive tasks have been developed by cognitive psychologists, not professional gamification designers, and for scientists, the clinical effectiveness of a gamified task is important, with less focus on employing effective and creative gamification designs [41]; (2) a variety of gamification techniques have been applied to cognitive tasks [9,24,38]; (3) gamification techniques have been applied to different cognitive tasks [24]; and (4) the results obtained from gamified cognitive tasks are often preliminary and limited by small sample sizes. Also, the considered duration for evaluating the efficacy of gamified tasks is relatively short [9,23-25,42,43].
There are recommendations and design guidelines to integrate game elements into cognitive tasks (eg, [9,30]). However, to our knowledge, they did not propose a detailed and step-by-step framework that clearly shows what factors are essential to designing gamification in these tasks from early stages (eg, planning and preparation phases) to develop, evaluate, and disseminate gamified tasks, followed by monitoring the efficacy of such tasks in the long term. In general, several gamification frameworks have been developed by experts, not designed for cognitive tasks (eg, [44-53]). However, they suffer from 3 main limitations: (1) Most of them have been designed for enterprise and business contexts, with less focus on health contexts [54]; (2) cognitive tasks need to engage participants for the long term, but existing frameworks have not been designed for this purpose [54,55]; and (3) they have not specified how game elements should be added to a particular context. Incorporating game elements in cognitive tasks may jeopardize data quality by imposing an additional cognitive load to these tasks [56]. For example, Katz et al [25] gamified the N-Back task by including a real-time scoring system while completing the task. The gamified task, in comparison to the actual task, negatively impacted data quality. One possible explanation is that the game features imposed irrelevant cognitive demands by distracting the players’ attention.

Objectives

Despite the papers that have shown mixed findings of using game elements in cognitive tasks, we assume that gamification can positively influence data quality and user engagement. Therefore, we are proposing a framework to guide the process of incorporating game elements in cognitive tasks by synthesizing (1) existing gamification design frameworks, (2) gamification efforts in cognitive assessment and training, and (3) field experiences.

Methods

Overview

We approached the research problem through the design science research (DSR) methodology [57]. Design science is an accepted research methodology in information systems. It emphasizes that research should be firmly grounded in existing knowledge and target the context in which the developed artifact must be used, to create scientifically sound artifacts (eg, theories, models, and methods) [58]. The 2 main steps for conducting DSR include (1) developing artifacts and (2) evaluation of the developed artifacts [53]. In our DSR approach, similar to Morschheuser et al [53], we employed an assembly-based situational method engineering methodology proposed by Brinkkemper [59]. Method engineering is an approach in information systems to develop new methods from recognized fragments of existing methods knowledge to propose a situational method tuned to the situation of the project at hand. According to method engineering, 3 phases are needed to develop a new method [59]: (1) building a method database, which includes all the resources required for the development of a new situational method; (2) constructing the situational method through assembling of the methods fragments from the method database; and (3) evaluation of the developed method. Figure 3 provides an overview of our assembly-based situational method engineering.
Knowledge Base

Defining Sources of Evidence

We selected the following 3 resources to gather the knowledge required for proposing the intended framework: (1) studies that proposed a gamification design framework, since by synthesizing them, we could extract the general framework for the design of gamification; (2) projects that used gamification in cognitive assessment or training to extract key factors and considerations for gamifying these contexts; (3) the experiences of relevant experts to integrate the evidence from live environments.

Exploring Relevant Papers

We used systematic literature review strategies in the Google search engine, Google Scholar, PubMed, and Research Gate to use a wide variety of relevant papers. The search was started in May 2017 and lasted until the submission date. Two search strings were developed based on keywords, their synonyms, and related terms: (1) (“gamification” AND (“framework” OR “platform” OR “process” OR “method”)) AND (2) (“game” OR “serious games” OR “game up” OR “video game”) AND ((“cognitive” AND (“training” OR “assessment”)) OR “Go/No-Go” OR “N-Back” OR “MMSE” OR “MoCA” OR “ADHD” OR “stop-signal task” OR “dyslexia”). Furthermore, search strategies such as checking the reference lists of included studies and cited reference searching were applied.

Inclusion Criteria for Selecting Gamification Frameworks

To select the most highly regarded gamification frameworks, the following 4 metrics were used: (1) framework was not focused on the parts or steps of the gamification design process, but covering the maximum number of steps; (2) framework was refined based on the feedback collected.

After extracting each piece of evidence and then applying it to the under-development framework, the whole of the framework was visualized for expert evaluation. Then, the framework was refined based on the feedback collected.

Method Base

Extracting the General Gamification Framework

After comparing the selected frameworks in terms of main characteristics, merits, and demerits, 2 general gamification design frameworks were elaborated. The first framework was based on analyses presented in Multimedia Appendix 1. The second framework was based on the Mechanics, Dynamics, Aesthetics (MDA) process, a formal framework for designing and analyzing games [60], and 2 adapted versions of MDA presented in [44,52], now known as Objects, Mechanics, Dynamics, Emotions (OMDE). The phases and activities of these frameworks will be described in detail in the subsequent sections while describing the proposed framework.

Customizing the General Gamification Frameworks for Cognitive Assessment and Training

An exhaustive number (n=63) of empirical project reports or theoretical works that applied gamification into cognitive tasks were gathered to customize the obtained general frameworks for cognitive assessment and training contexts. We tried to extract an abstract process for each paper by observing the papers’ different sections. As abstracted in Figure 3, most articles did not use a specific or formal framework for gamifying cognitive tasks. Therefore, either we could not extract a process,
or the process obtained consisted of only one chunk. Finally, the isolated processes, fragments, and general gamification frameworks were converged based on their commonalities and unique features to assemble the intended framework.

**Results**

**Search Results**

**The Explored Gamification Design Frameworks**

We identified a total of 35 gamification design frameworks (these frameworks are listed in Multimedia Appendix 1). Of these, 11 frameworks were selected for more in-depth analysis (these frameworks are highlighted in bold in Multimedia Appendix 1).

**The Explored Gamification Projects in Cognitive Assessment and Training**

A total of 63 gamification projects in cognitive assessment or training was selected. Of these, 41 (41/63, 64%) were empirical project reports; 2 (2/63, 3%) used empirical and theoretical methods, and 20 (20/63, 32%) were theoretical. As for the purpose of the papers, 22 (22/63, 35%) were for assessment, 32 (32/63, 51%) for training, and 9 (9/63, 14%) for both assessment and training. In addition, 19 (19/63, 38%) were for children aged 3-14 years; 16 (16/63, 34%) for adolescents, youth, and adults aged 15-55 years; and 13 (13/63, 28%) for older adults aged 56-94 years. For more details and raw data about the works included, such as their targeted cognitive functions or impairments, please see both tables in Multimedia Appendix 2.

**The Proposed Framework**

**Overview**

To address the need for a framework that more effectively integrates game elements into cognitive assessment and training, we introduce a framework consisting of 7 phases: (1) preparation; (2) knowing users; (3) exploring existing tools for assessing or training the targeted cognitive context and determining the suitability of game-up and mapping techniques; (4) ideation; (5) prototyping using OMDE; (6) development; and (7) disseminating and monitoring. These phases are grouped into 3 overarching categories: predevelopment, development, and postdevelopment (Figure 4). Although the framework phases are presented sequentially, they are not necessarily to be conducted linearly since different ideas and directions may be explored while integrating gamification into targeted cognitive tasks. Therefore, projects are encouraged to loop back through the phases continuously [61,62].

![Figure 4. The proposed framework. OMDE: Objects, Mechanics, Dynamics, Emotions.](image)
Phase 1: Preparation

The primary purpose of the preparation stage is to have a good understanding of a gamification project’s objectives [53,66]. Defining objectives has been recommended in most reviewed gamification frameworks (9 of 11) and will support a later stage to figure out if the desired goals have been achieved [66]. The interdisciplinary team should list all potential objectives and then rank and justify the list in terms of importance since trade-offs of less important goals for more important ones might be needed [49,53]. Finally, as the team goes through gamification design and development, it can go back to the list to focus on what is really important [49]. Therefore, the defined objectives should be achievable, specific, relevant, measurable, and time-bound [66]. For instance, an initially broad goal of “increasing participants’ motivation to complete their cognitive training exercises” may be refined to “conduct 10 minutes of training each day.”

According to frameworks such as [50,53,66], gamification’s suitability as a possible way to intervene should be examined before starting any gamification design process. It can be carried out by detecting the problem that gamification should solve by gathering and analyzing quantitative and qualitative information. After determining the problem, the root reason that caused the problem must be motivational. Otherwise, gamification is not suitable [66]. The root reason can be identified by the “Five Whys” technique that determines the root cause of a problem by repeating the question “Why?” [67].

It is also essential to identify the standard project requirements and constraints such as scope (time, personnel, budget) and legal and ethical constraints since they can affect a gamification project’s success [50,53].

Phase 2: Knowing Users

During this stage, the interdisciplinary team must select one or more of a variety of methods to collect information about target users’ motivations and needs (eg, interviews, observation of target users’ behaviors, surveys, focus groups, questionnaires) [50,53]. After collecting and analyzing users’ data, users with similar characteristics should be segmented into groups to create user personas. The segmentation helps the team choose a more acceptable design to gamify targeted cognitive tasks.

Typically, gamification through motivational affordances enriches information systems [53]. Therefore, it is essential to conduct this phase (9 of 11 frameworks have had one step for understanding users). People are motivated by different motivational affordances based on characteristics such as their age, gender, and culture. The Octalysis gamification framework is widely used to segment users based on their motivations [68]. Octalysis was developed by Chou [68] as an octagon with 8 core drivers of individuals on each side: (1) epic meaning and calling, (2) development and accomplishment, (3) empowerment of creativity and feedback, (4) ownership and possession, (5) social influence and relatedness, (6) scarcity and impatience, (7) unpredictability and curiosity and, (8) loss and avoidance. The game strategies or elements that are associated with each driver have been grouped next to it.

In cognitive contexts, in addition to considering the users’ motivations, their needs should be identified since they may suffer from mild to severe cognitive dysfunction, which may sometimes be accompanied by physical disabilities. Afrasiabi Navan and Khaleghi [7] developed the game “Smile 1” to help Iranian autistic children recognize emotional states such as happiness, sadness, anger, and fear in the cartoon faces of girls and boys that appear in the game. The girls have a scarf (Figure 5) since these children only identify women and girls who wear a scarf (in Iranian culture, girls and women wear a scarf). To identify users’ needs, most gamified assessments and training have tried to implement a gamified experience that allows users natural and straightforward interactions, often using touch-based technologies such as smartphones and tablets (22 of 63). For more information about designing a user-friendly interface for people facing cognitive and physical disabilities, please see [2,69-73].

Figure 5. Screenshot of the game “Smile 1,” which was developed to help autistic children recognize different emotions [7].

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Phase 3: Exploring Existing Tools for Assessing or Training the Targeted Cognitive Context and Determining the Suitability of Game-Up and Mapping Techniques

At this stage, the interdisciplinary team should thoroughly acquaint itself with existing tools for assessing or training the targeted cognitive functions or impairments through methods such as consulting with cognitive experts and gathering quantitative and qualitative information. This work helps the team incorporate game elements into these tools without changing their process and execution and find integration points for adding game elements [74]. Describing the tools at a granular level is required. Otherwise, it is not guaranteed that the next framework steps will lead to the desired outcomes [53,74]. Three main tools that can be explored for cognitive assessment and training purposes are standard computerized or not computerized cognitive tasks, existing cognitive games, and existing video games.

For standard computerized or not computerized cognitive tasks, there may be more than one cognitive task designed to assess or train a cognitive function (eg, continuous performance test, Go/No-Go test, stop signal task for assessing attention, inhibitory, and motor skills). Selecting appropriate cognitive tasks is very important. Some tasks may have better performance than others [24,75]. Valladares-Rodriguez et al [75] chose the California Learning Verbal Test II to assess episodic memory. The task, in comparison to other tasks such as the Children's Memory Scale, Rey Auditory Verbal Learning Test, and Wechsler Memory Scale, has a large number of variables and produces more qualitative information. Computer versions have now been made for many standard cognitive tasks, which are cheaper, more repeatable, and easier to administer and distribute [76]. Many of these tasks can be found in [77-79].

Regarding existing cognitive games, many games have been developed based on standard cognitive tasks [80]. It is beneficial to find these games since they can be reused for current cognitive assessment and training purposes, or the initial inspiration for gamifying current tasks can be obtained by reviewing the style of these games for integrating game elements into a cognitive task [25,33,43,75]. Brain games can be found from platforms such as Cogmed [13], Nintendo Brain Age [14], Lumosity [15], and Posit Science BrainHQ [16].

Regarding existing video games, it has also been demonstrated that classical video games of different genres that have not been inherently designed to assess or train cognitive functions can be reused as a standard cognitive task. Video game challenges come in various forms, and players have to use their underlying neural systems and cognitive abilities to win these games [81-90]. Each cognitive function is typically characterized by a set of parameters estimated from a gameplay to reuse for assessing and training. In other words, the team must identify which cognitive skills are central to each gameplay [91]. For winning games like Tetris and Candy Crush, mental rotation and spatial reasoning skills are required [91]. Card games like Solitaire and FreeCell have a reasonable correlation with classical measurements of executive functions and planning abilities [92,93]. The team can explore existing games from platforms such as the App Store and Google Play. They rank games based on their rate of downloads and players' comments, which help select games according to the target user's preferences. According to Green and Bavelier [83], Doherty et al [91], and expert experiences, it is unnecessary to find appropriate games through earlier methods for categorizing games such as genre-based methods since they are no longer effective. Games that have never overlapped in terms of content and mechanics now have many points of overlap [83].

After collecting the tools, the interdisciplinary team should determine whether game-up and mapping techniques can be used instead of designing a new gamified cognitive task from scratch. Game-up refers to adding game elements such as colors, animations, sound effects, and a backstory into standard cognitive tasks without changing their fundamental properties such as stimuli, design, and procedure [5,26,94] (21 of 63 studies used the game-up technique). The developed gamified cognitive tasks based on game-up are often presented in the form of a battery of mini-games. Each mini-game focuses on a specific cognitive function (eg, [64,76,95]). For example, Zeng et al [76] gamified a computerized cognitive test battery to detect impairments in 5 cognitive functions involved in developing a major neurocognitive disorder. For each test, some mini-games were designed in the context of ADLs such as cooking, cleaning, and shopping. The main feature of game-up is simplicity in terms of its mechanics and design [7,65,96,97]. This feature is useful for individuals who suffer from cognitive impairments like children with learning disabilities and ADHD who have weak working memory capacity [65,96]. Therefore, gamified cognitive tasks for these children should be broken into short and discrete tasks [65,96]. Mapping refers to reusing an existing game (cognitive and classical games) as a cognitive task and can save considerable time and effort that have been applied in the design of explored games [98,99]. The mapping technique was used by 21 of the 63 studies (eg, [72,92,93,100-104]). Explored games should be adjusted appropriately since they usually do not provide cognitive psychologists with sufficient quantitative data about the participant’s performance and progression on one hand. On the other hand, the used game elements and storylines may not align with participants' preferences. According to Green and Bavelier [83], Doherty et al [91], and expert experiences, it is unnecessary to find appropriate games through earlier methods for categorizing games based on content, design, and structure [83]. Each game's structural characteristics should be examined individually since different games, even those that fall into one category such as action or first-shooting person, may require greatly different cognitive demands [81,85,107,108]. In mapping, it is also possible to mash up various games for cognitive assessment and training purposes [81]. For example, dyslexia is associated with a variety of underlying deficits in phonological, auditory, motor, memory, and visual attentional processes. According to previous findings showing the core deficit in dyslexia is related to attentional problems, Franceschini et al [81] explored 10 action games to train dyslexic children. Action games can enhance a wide variety of visual attentional abilities, such as segmenting items both in time and across space.
Phase 4: Ideation

The interdisciplinary team is involved in a highly iterative design process through the next 3 phases (ideation, prototyping using OMDE, and development). Iterative processes enable the team to obtain more creative and effective gamification designs. Of the 11 frameworks, 5 have one or more steps that should be iterated until the desired designs and outcomes are reached (ie, [46,48-50,53]). The steps that are often performed iteratively are ideation, prototyping, and development [53].

At this stage, the team combines the analyses and materials obtained in new ways to produce apt and innovative ideas to engage target users. It is necessary to involve a cross-functional group of people from cognitive experts, gamification designers, and target users to start this stage [61,62]. This work helps the interdisciplinary team to collect a greater number of more varied and creative ideas [61,62]. The participants should be encouraged to use different ways to be creative [61,62]. Brainstorming, co-creation workshops, and mind mapping are some methods [53,61,62]. The important question at this stage is how to help participants find the ideas. One solution is to explore existing games, gamification designs, and examples that may be a perfect fit for the current project [62]. For instance, in the game “Whack a Mole,” moles hide quickly, and the player trying to hit them with a hammer has to be faster. Various types of moles exist in different game versions, such as ninja, pirate, samurai, and batman moles [109]. Based on studies reusing the Whack a Mole to measure attention, inhibitory control, and executive functions [72,102,103], one idea is to use ninja and samurai moles as metaphors for Go and No/Go stimuli, respectively. As a result, a gamified cognitive task that mimics the Go/No-Go design can be created using the Whack-a-Mole style. Exploring many games and gamification examples and then mashing them up to fit the current problem is another right approach for generating ideas to gamify the current task [62].

After preparing ideas, similar ideas should be clustered using affinity diagrams; then, the clusters should be prioritized using methods such as dot voting. This work helps the team to focus on important ideas in the next 2 phases [50,53].

Phase 5: Prototyping Using OMDE

After collecting the right ideas, the interdisciplinary team needs to start prototyping. Prototyping is the stage in which the team implements the ideas into tangible forms to see how they actually work. In this stage, low-fidelity (ie, “quick and dirty”) prototypes are developed rapidly to gather feedback from relevant experts and target users early and often [61]. Prototyping saves time and resources by helping the team to identify refinements required before solidifying a design [61,62].

During each iteration of the prototyping, the team can use the OMDE design guideline to (1) check the motivational characteristics of prototypes (such as fun, flow, engagement, positive emotions) and (2) validate prototypes from cognitive psychology aspects. OMDE divides the components of a gamified cognitive task into 4 categories: objects, mechanics, dynamics, and emotions. Objects are a gamified cognitive task’s assets, such as visual assets, images, audios, videos, and animations [60]. Mechanics refer to a gamified task’s components at the level of game rules, algorithms, and data representation [60]. Dynamics are run-time users’ behaviors that emerge as users partake in the gamified task such as competition and cooperation [60]. Emotions refer to whatever emotions users experience while interacting with the gamified task [44]. Participants may experience different emotions such as fear, happiness, anger, sadness, and pride while interacting with the gamified task [44]. Dynamics and emotions emerge from the selected objects and mechanics [44,52,60]. For instance, a leaderboard mechanic leads to dynamics such as competition and comparison and emotions such as fear and happiness. Some participants may be afraid of being judged by others, and the use of the leaderboard may demotivate them from continuing the gamified task. Or, many participants may enjoy these dynamics, and the leaderboard can motivate them. Therefore, displaying participants’ statuses in the leaderboard must be an optional feature in a gamified task.

Good dynamics and emotions are vital to ensuring a strong user commitment to participation [44,52,60]. To check gamified tasks’ motivational features with OMDE, the interdisciplinary team must first define the desired dynamics and emotional responses that the designed task should evoke among users. Then, in each iteration, the team must list what dynamics and emotions emerge from the gamified task in practice and then compare the responses with the desired ones to determine if the desired responses have been reached. The team cannot accurately predict what dynamics and emotions will emerge from a gamified task. Therefore, it is necessary to use OMDE iteratively [44,52].

In gamified cognitive tasks, it is also essential to validate the components of OMDE from cognitive aspects because they may impose an additional cognitive load. Objects and mechanics can cause difficulty in categorizing cognitive tasks’ stimuli for participants or can evoke emotions such as anxiety and stress that may distract participants’ attention from completing gamified tasks [19,23-25,33,65]. In this circumstance, participant errors increase, and the reliability of the data obtained decreases. For instance, in the study by Birk et al [23], the gamified Go/No-Go task decreased users’ performance. In the standard task, a sequence of stimuli is presented for 500 ms. Participants should respond to circles but not to squares. In the gamified version, participants should shoot blond zombies (Go stimulus) but not yellow hat moles (No/ Go stimulus). In the standard task, a circle is very different from a square. In contrast, in the gamified task, the colors of yellow hat moles and blond zombies are close to each other and can cause difficulty while participants are trying to identify the gamified task’s stimuli. In order to gamify the Go/No-Go task, Lumsden et al [19] suggested that red and green colors be used instead of cartoon characters because participants are more familiar with colors. The components of OMDE can be validated by discussions with cognitive experts and answering questions such as: (1) Is it possible to gamify the cognitive tasks’ stimuli? If yes, how can we do so? (2) Does the team have the freedom to choose objects for gamifying cognitive tasks, or should they be selected among those listed in a specified set or ones that participants are more familiar with, such as everyday objects? (3) What degree of structural similarities (such as shape, size, and color) between
objects and mechanics should be adjusted? (4) Is it possible to gamify the surrounding environment of the selected cognitive tasks’ stimuli? If yes, how should the degree of separation between cognitive and gamified sections be adjusted? (5) Does the designed gamified cognitive task lead to negative emotions like anxiety and stress?

**Phase 6: Development**

During this stage, actual gamified cognitive tasks are developed through frequent consultation with relevant experts (gamification and cognitive experts) and regular testing with target users (Figure 6). Based on the examined gamification efforts in cognitive tasks, to test the efficacy of gamified tasks, rigorous evaluations are required in terms of user engagement and data quality (eg, [9,19-21,23-27,34,38-40]).

![Figure 6. Overall structure of the development phase.](image)

Two methods are widely used to evaluate how gamified cognitive tasks influence users’ engagement and motivation [24,27,38,39]: (1) subjective measures of engagement, in which the motivation level of a gamified task is measured through self-report questionnaires based on SDT [31] and Flow [32] theory (eg, Flow State Scale [110]) and (2) objective measures of engagement such as the number of times participants used a gamified task or the number of optional cognitive assessment or training sessions performed by participants, methods that might be more preferred by the interdisciplinary team [24,38,39,63,111]. A combination of both methods is often used to measure gamified tasks’ motivation levels [24].

To assess how gamified cognitive tasks impact the quality of data and to indicate the maturity of these tasks to be used as a valid clinical tool, they must be evaluated for 2 essential properties [43]: (1) reliability, which refers to the extent to which a task’s results are consistent and repeatable, and there are 4 types of reliability (test-retest reliability, parallel forms reliability, internal consistency reliability, and interrater reliability) and (2) validity, which refers to how well a task measures what it claims and includes criterion validity, content validity, construct validity, face validity, external validity, and ecological validity.

In cognitive training, it may also be necessary to measure to what extent gamified tasks can impact transfer effects [38,41,83]. The term “transfer” is frequently used in clinical practice and refers to the extent to which considered cognitive training tasks can improve untrained cognitive abilities. New tasks and situations are included to measure transfer effects. Transfer effects are divided into near and far transfer effects. Cognitive training has near transfer effects if it improves cognitive skills that are highly similar to trained cognitive skills. Far transfer effects refer to improvements in cognitive skills that are less similar to trained skills.

There are 2 other essential factors for conducting rigorous evolutions: (1) selecting sufficient sample sizes and (2) selecting an appropriate duration for evaluation. Most gamification efforts in cognitive contexts have used small sample sizes to evaluate the efficacy of gamified cognitive tasks [9]. Also, little consideration has been given to using statistical analyses such as power analysis for a sample size calculation [9,112]. For more information about how to calculate sufficient sample sizes, please see [113,114]. Insufficient sample sizes limit the reliability and generalizability of the results [9,115,116]. Moreover, only a few studies have used randomized controlled trials (RCTs) to evaluate gamified cognitive tasks [30]. In clinical research, RCTs are considered the most robust study design for evaluating the effectiveness of a new tool due to the ability of RCTs to minimize several forms of bias [61]. RCTs randomly assign participants to an experimental group and a control group. The use of an RCT design comparing gamified (experimental group) and nongamified (control group) versions of the same cognitive task has been highly recommended to evaluate the potential efficacy of gamified tasks [9,30]. Regarding selecting the appropriate duration for evaluation, participants are not involved in the gamified task over the long term but instead participate for a short time. In turn, it remains unclear after how long participants feel boredom and how the quality of data will alter in these circumstances [19,25].
Moreover, a short duration can cause errors due to participants' unfamiliarity with the gamified task. In this regard, using short tutorials and warm-up sessions before actual evaluation sessions has been recommended [65,76].

**Phase 7: Disseminating and Monitoring**

Once the gamified cognitive task’s efficacy has been demonstrated in the previous step, the task is finally disseminated to its target audience. There have been long calls for disseminating and sharing well-evaluated digital health interventions due to the abundance of low-quality interventions currently available to the public [17,61]. Disseminating gamified tasks can be access to the broader population that may benefit the most from these tasks and helps the industry invest in these interventions more quickly [61,73]. Disseminating can occur via the App Store or Google Play. Also, industry partnerships can support a more effective and sustainable dissemination of gamified cognitive tasks [61,117]. It is also highly recommended that projects disseminate their findings, experiences, and methods for developing gamified cognitive tasks to scientific journals, conferences, researchers, and digital mental health intervention developers. It can advance future gamified tasks and improve their effectiveness [61,117]. Disseminating can also include open sharing of gamified cognitive task codes via GitHub [118] or allowing free access to a mobile health platform such as Mobile Sensor Data-to-Knowledge (MD2K) [119].

For disseminating gamified tasks, 2 other important factors should be considered by the team. First, according to expert experiences and [91] in collaboration with cognitive experts, appropriate guidelines and prescriptions should be prepared for using gamified cognitive tasks by clinics and target users (eg, determining the minimum effort and time that target users should spend to improve their cognitive skills). These instructions help mental experts and target users to use gamified tasks effectively. Second, ethical concerns are another primary concern that should be considered in this stage since performance variables are embedded in gamified tasks to track improvements in users’ cognitive functions. Therefore, gathering target users’ information should be undertaken with their explicit consent [23,47,50,53,73].

After disseminating, gamified tasks’ performance should also be accompanied by postlaunch monitoring and evaluation, in which usage and applicability of the gamified task through methods introduced in the previous phases are observed in regular intervals to compile a list of possible improvements [47,53]. For instance, different levels of cognitive impairments may exist among users, and after a cognitive training program through the gamified task, users’ cognitive status may improve. Therefore, according to the users’ new levels, some changes may need to be applied in the gamified task [69,73]. Also, gamified tasks’ motivation levels should be continuously monitored to maintain intrinsic motivation for the long term. The initial effects of game elements can diminish over time [47,53].

**Discussion**

**Overview**

This paper proposes a 7-step framework to guide the design, development, and evaluation of gamified cognitive tasks designed to assess or train cognition. Within these steps, there are a series of key recommendations on how each step should be operationalized. Along with the framework, the article presents the OMDE guideline at stage 5 of the framework (prototyping using OMDE), which contains vital recommendations for advancing the understanding of design complexities when applying gamification in cognitive tasks.

The prototypes of the framework were designed and evaluated extensively by evidence from 3 sources: (1) existing gamification design frameworks, (2) project reports of applying game elements into cognitive assessment and training, and (3) expert experiences. To our knowledge, this is the first study of its kind that has converged these sources to propose a unified model to design gamification in cognitive tasks. The significant point about gamification efforts in cognitive tasks is that they do not use a specific design process to incorporate game elements. We used an alternative solution, such that by observing each work, we tried to extract clues or pieces of information to propose an abstract process for each of them, if possible. This work helped us to identify critical factors and considerations for gamifying cognitive tasks.

**Comparison of the Proposed Framework With General Gamification Frameworks**

Like general gamification frameworks, the proposed framework follows a user-centered design to improve users’ participation but has many added features that make it appropriate to gamify cognitive tasks. One main finding of this study that gamification designers need to be aware of is that an intermediate design is required for gamifying cognitive tasks, meaning that game elements cannot be selected without considering the targeted cognitive context characteristics. Otherwise, an irrelevant cognitive load may jeopardize data quality. Therefore, collaboration between both gamification and mental experts is required to examine the interplay of game elements and cognitive processes [9]. The intermediate design is a crucial feature that differentiates the gamification design framework required for cognitive assessment and training from other contexts. Based on examined gamification efforts in cognitive tasks, we concluded that 2 techniques have been widely used to gamify cognitive tasks besides designing a new gamified task from scratch: (1) gaming-up an existing cognitive task and (2) mapping an existing game (cognitive and classical games) to a cognitive function or impairment to assess or train it. The required details to use game-up and mapping techniques were provided in step 3 of the framework as far as possible.

**Limitations**

The main limitation was that only a few studies have discussed how game elements impact participants when interacting with the gamified task and how they should be utilized in cognitive tasks to positively influence data quality and user engagement. Gathering evidence from the mentioned sources only gave an
initial evaluation for the proposed framework because the number of experts and relevant studies was limited. Hence, a more robust evaluation is necessary. For this purpose, we listed most of the recognized experts in the area to evaluate and refine the framework in subsequent studies.

Possible Future Studies

By further developing the framework exploited in this work and utilizing machine learning and deep learning algorithms, it is possible to create a recommender system that can suggest the most appropriate game elements according to characteristics of the targeted cognitive context and users’ preferences or requirements. In our work, only existing games that have been developed or examined in scientific papers were investigated. It is also possible to analyze a great number of current games, from brain games to classical games, for further development of the framework. Due to the time constraints, establishing the feasibility of proposing different gamification design frameworks for cognitive functions that inherently share similar cognitive processes like processing speed (Gs) and working memory [20] was not provided.

Conclusions

While more work is needed to further refine and evaluate the framework, we believe our framework has great potential to be used as a foundation for developing effective gamified cognitive tasks. Furthermore, ideas presented in the paper can be further developed and researched by many other researchers and practitioners.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Explored gamification design frameworks. [DOC File, 100 KB - games_v9i2e21900_app1.doc]

Multimedia Appendix 2

Included papers applied gamification in cognitive training/testing. [DOC File, 231 KB - games_v9i2e21900_app2.doc]

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Abbreviations

ADHD: attention deficit hyperactivity disorder

ADLs: activities of daily living

CAM: Confusion Assessment Method

DSR: Design Science Research

MD2K: Mobile Sensor Data-To-Knowledge

MDA: Mechanics, Dynamics and Aesthetics

MMSE: Mini-Mental State Examination

MoCA: Montreal Cognitive Assessment

OMDE: Objects, Mechanics, Dynamics, Emotions

RCT: randomized controlled trial

SDT: self-determination theory

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Leaderboard Design Principles to Enhance Learning and Motivation in a Gamified Educational Environment: Development Study

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Abstract

Background: Gamification in education enhances learners’ motivation, problem-solving abilities, decision-making abilities, and social skills such as communication. Numerous ongoing studies are examining the application of gamification design methodology and game mechanics to a learning environment. Leaderboards are a type of game mechanic that assist learners in goal setting and unleash the motivation for learning.

Objective: The aim of this study was to develop leaderboard design principles to assist learners in efficient goal setting, improve learning motivation, and promote learning in gamified learning environments.

Methods: This study implemented 2 different strategies. First, we analyzed previous research on leaderboards that focus on educational efficacy and influence on social interactions. Second, we collected and analyzed data related to cases of leaderboards being used in educational and sport environments.

Results: This study determined 4 leaderboard design objectives from previous studies. Based on these objectives, we developed 3 leaderboard design principles. First, macro leaderboards and micro leaderboards should be designed and used together. Second, all the elements used to measure learners’ achievements in an educational environment should be incorporated into the micro leaderboard. Third, leaderboards should be designed and considered for application in contexts other than learning environments. This study further analyzes best practices considering the 3 leaderboard design principles.

Conclusions: This study contributes toward resolving problems associated with leaderboard design for the application of gamification in educational environments. Based upon our results, we strongly suggest that when teachers consider applying gamification in classrooms, the leaderboard design principles suggested in this research should be incorporated.

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KEYWORDS
leaderboard design; gamification; learning motivation; affordance

Introduction

Recent advances in technology have caused our methods of communication and our lifestyles to evolve at an unprecedented rate. However, this has not necessarily been the case in the field of education. Although there has been some technology advancement in the classroom, such as the introduction of digital devices to replace books, knowledge is mostly delivered to learners in one direction by the teacher. Currently, researchers are actively studying diverse educational methods such as problem-based learning and learner-centered educational environments [1]. Gamification, which means using gaming elements, structures, and principles in educational innovation, is attracting the attention of teachers and instructors.

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Gamification uses game mechanics such as points, badges, levels, or avatars to motivate participants by providing flow and fun experiences while promoting social interaction among participants [2,3].

The application of gamification in the learning context is called “gamification in education” [4]. Al-Azawi et al [5] conducted a comparative analysis of gamification, game-based learning, and educational games, which are mechanics that represent educational innovations based on game thinking. They found that gamification is easier to achieve and more affordable than other methods and that it encourages learners to undertake new challenges without fear of failure. Considering the research of Al-Azawi et al, this study confirmed the trends of gamification, game-based learning, educational games, and serious games by using a Google Trends search (Figure 1). The results showed that gamification has been receiving worldwide attention and popularity since 2012. Park and Kim [6] collected 754 cases of gamification from pre-2010 to 2017, 270 of which were related to education.

Figure 1. Trends of gamification, game-based learning, educational games, and serious games by using the Google Trends search.

Gamification in education is beneficial to learners in several ways. Majuri et al [7] collected 807 studies related to gamification in education from June 2015 and performed an empirical study on 128 relevant studies. Their findings revealed that game mechanics unleash and improve affordance, immersion, and the social behavior of learners. Psychological benefits include improvements in cognitive and emotional ability, stimulation of the desire to be challenged, increased social interaction, projection of psychological states and traits, and the enhancement of personal traits. Behavioral outcomes include improved learning performance, engagement, and physical and social interactions. Kim et al [4] suggested the Lean Canvas-based 4F Process for more efficient gamification design. The Lean Canvas-based 4F Process is a methodology that analyzes the objects of gamification, player type, fun preferences, and game genre preferences to help users set game mechanics and develop prototypes. Meanwhile, Mora et al [8] analyzed 18 studies on gamification design methodology for the period 2011 to 2015 and identified 5 gamification design elements. These elements are as follows:

1. Economic: objectives, risk, return on investment, and stakeholders
2. Logic: loop, end game/epic win, on-boarding, rules
3. Measurement: metrics and analytics
4. Psychology: fun, motivation, socialness, desired behaviors, and ethics
5. Interaction: narrative, user interface/user experience, and technology

Octalysis [9] is a published gamification design framework for the development of gamified learning content that is based on human behavioral characteristics, cognitive structure, and the Gamified Environment and Learning Design model [10]. Game mechanics design is one of the most important elements shared by the published gamification design methodologies. Game mechanics represent the physical and environmental elements connecting users and games [11]. Through game mechanics, affordance is achieved and values nested in the content are transmitted to players [12].

Leaderboards, among other game mechanics, assist users with goal setting, boost competition, and provide feedback. Dicheva et al [13] conducted systematic mapping of 34 studies related to gamification in education published between 2011 and 2014. Their results showed that leaderboards were the most frequently used method—after badges—in the 34 studies. Goal setting is extremely important in educational environments [4]. A leaderboard is a device that guides learners to set specific goals and that represents the outcome in a visible way [7]. However, detailed leaderboard design methods are not addressed in existing gamification design methodology. Kim et al [4] state that a leaderboard should be designed at micro and macro levels but did not mention the structural arrangement of the elements. Despite all the existing research on the effects of leaderboards, their organization has been rarely addressed. This study,
Individuals with a positive mindset tend to employ upward counterfactual thinking. For example, a learner ranked seventh on the leaderboard may consider the learner ranked third and think, “If I had worked a little harder, I might have ranked third.” Conversely, when people have negative experiences, they tend to employ downward counterfactual thinking. For example, a learner ranked 20th on the leaderboard might think, “I dropped this time. I will probably drop further.” If this negative experience continues, the individual may lose the confidence and motivation for learning. Based on the literature review, this study suggests the following objectives that should be considered in the design of leaderboards:

Objective 1: Minimize relative deprivation.

Objective 2: Minimize learners’ experiences of failure to minimize downward counterfactual thinking.

Objective 3: Maximize learners’ experience of success to induce upward counterfactual thinking.

Structure of Leaderboards in a Gamified Learning Environment

Leaderboards can be divided into 2 types: macro leaderboards, which are associated with overall content, and micro leaderboards, which are associated with a subsection of content. Figure 2 displays the player versus player ranking in the World of Warcraft. Figure 3 is a badge count leaderboard for Khan Academy—a gamified learning platform for mathematical education. This figure shows the number of badges granted to the learners who satisfied the criteria specified by the Khan Academy. According to the standards suggested by Kim et al [4], Figure 2 is a macro leaderboard while Figure 3 is a micro leaderboard. Although these leaderboards serve different purposes, the structural characteristics in these leaderboards are similar. The player profiles are provided. The leaderboards in games offer information, including ranking, ID or nickname, organization, occupation in the game, character information, and the player’s win rate. The information includes rank, grade, experience, and earned badges. Game players meet and compete in the game and the information is reflected on the leaderboard. The same is true of the gamified learning environment.

After conducting learning activities in the classroom, teachers assess the results and update them on the leaderboard. Based on the information registered on the leaderboard, learners maintain motivation for learning, compete with other learners, and set specific goals for themselves. Therefore, it is important that the leaderboard provides specific information. At the same time, the leaderboard should function smoothly to maintain the user-friendly and fun experience of the gamified learning content or environment.

Methods

Learners’ Self-feedback and Goal-Setting Via the Leaderboard

Leaderboards, as game mechanics, induce social behaviors and encourage interaction among participants through competition and cooperation. Learners are self-motivated to check their positions on the leaderboard and stimulate to inform others of their accomplishments. According to O’Donovan et al, leaderboards influence learners’ motivation more than other game mechanics such as progress bars, end prizes, and awarded badges. However, leaderboards cannot be used alone; they provide information for learners in conjunction with other game mechanics. Teachers assess the performance of the learners and award points, levels, and badges accordingly. Additionally, teachers display who scored how many points and badges and who is at which level on the leaderboard. Learners can see their ranking on the leaderboard, compare themselves with other learners, and receive feedback on areas where they need to improve. Gamification helps learners to immerse themselves in learning with enthusiasm and persistence. As learners enter a state of flow in their learning, they set specific goals based on their level on the leaderboard. Learners can see their progress in the game and the information is reflected on the leaderboard. The same is true of the gamified learning environment. After completing learning activities in the classroom, teachers assess the learners who satisfied the criteria specified by the Khan Academy. According to the standards suggested by Kim et al [4], Figure 2 is a macro leaderboard while Figure 3 is a micro leaderboard. Although these leaderboards serve different purposes, the structural characteristics in these leaderboards are similar. The player profiles are provided. The leaderboards in games offer information, including ranking, ID or nickname, organization, occupation in the game, character information, and the player’s win rate. The information includes rank, grade, experience, and earned badges. Game players meet and compete in the game and the information is reflected on the leaderboard. The same is true of the gamified learning environment.

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Figure 2. World of Warcraft leaderboard.

![World of Warcraft leaderboard](image)

Figure 3. Badge count leaderboard of Khan Academy.

<table>
<thead>
<tr>
<th>No.</th>
<th>User</th>
<th>Badges Earned</th>
<th>Active/Inactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>cr4k3d 3gg</td>
<td>27,039</td>
<td>Inactive</td>
</tr>
<tr>
<td>2</td>
<td>Anthon van der Neut</td>
<td>20,083</td>
<td>Inactive</td>
</tr>
<tr>
<td>3</td>
<td>Kati Susanna</td>
<td>20,000+</td>
<td>Active</td>
</tr>
<tr>
<td>4</td>
<td>TJ</td>
<td>15,124</td>
<td>Active</td>
</tr>
<tr>
<td>5</td>
<td>KEVIN</td>
<td>13,684</td>
<td>Active</td>
</tr>
<tr>
<td>6</td>
<td>Wudafu</td>
<td>13,453</td>
<td>Inactive</td>
</tr>
<tr>
<td>7</td>
<td>Raymond Greenwood</td>
<td>12,453</td>
<td>Inactive</td>
</tr>
<tr>
<td>8</td>
<td>Alois</td>
<td>11,238</td>
<td>Active</td>
</tr>
<tr>
<td>9</td>
<td>Cyan Wind</td>
<td>11,211</td>
<td>Inactive</td>
</tr>
<tr>
<td>10</td>
<td>Blaze Runner™</td>
<td>11,166</td>
<td>Active</td>
</tr>
<tr>
<td>11</td>
<td>Quan Cheng Taian</td>
<td>10,972</td>
<td>Inactive</td>
</tr>
<tr>
<td>12</td>
<td>trek</td>
<td>10,892</td>
<td>Inactive</td>
</tr>
<tr>
<td>13</td>
<td>J Helston</td>
<td>10,750</td>
<td>Recently Active</td>
</tr>
</tbody>
</table>
Butler [26] examined the relationship between leaderboards and the fun experienced by players and 10 key findings were obtained. Those relevant to this research are as follows:

1. Players who have experienced competition play games at least once more than those who have not.
2. The level of fun experienced by players is not related to the number of plays.
3. Creating games that are too easy may downgrade the fun, depending on the player’s opinion.
4. High scores are not necessarily related to fun.
5. When players consider a game too easy, it is difficult to change their opinion; however, alternative definitions can be considered when it is deemed too difficult.

Appropriate competition induces a state of flow. In learning environments, macro leaderboards are used frequently. However, macro leaderboards can only provide numeric data totaling the performance of participants and can therefore only induce fragmented competition. Thus, many presume that frequent competitions between participants cannot be induced by design. Additionally, participants in upper ranks may be exalted by high scores, while those in middle and lower ranks cannot even entertain the thought of competing with those in higher ranks because of the gap in achievement. Therefore, leaderboards that reflect standards or elements that encourage competition in other areas are just as important as leaderboards that promote high scores. Considering the necessity of the following structural conditions in designing leaderboards based on our literature review, this study suggests the following structural purpose of leaderboard design.

Objective 4: Design leaderboards with measurable learning performance to induce learners to obtain high scores and compete with one another.

Results
Leaderboard Design Principles for Effective Gamified Learning
To achieve the 4 objectives identified from the analysis of prior research, this study suggests 3 design principles, as summarized in Figure 4.

Figure 4. Suggested structure for leaderboard design.

First, both macro leaderboards and micro leaderboards should be designed. If only macro leaderboards are used, participants in the mid and upper rankings can maximize their experience of success. Conversely, those who belong to the lower rankings on a macro leaderboard experience a sense of failure. If they are continuously recorded in the lower rankings on a macro leaderboard, their failure experiences accumulate and negative perceptions and experiences of learning are maximized [27]. To address this problem, learners require feedback to assure them that they are learning properly in some areas. Micro leaderboards fill this need by providing more detailed feedback than macro boards. Using micro leaderboards makes it easier to encourage the scoring of high points and frequent competition and to maximize success while minimizing failure.

Second, all the elements used to measure learners’ achievements in an educational environment should be incorporated into the micro leaderboard, as described in design principle 1. This allows participants to take part in learning activities in areas where they have confidence. Thus, learners realize an extended range of movement through leaderboard diversification and are consequently stimulated to achieve more in their learning [28]. Additionally, when the number of leaderboards increases, it is more likely that a learner will be listed in the upper ranks, resulting in increased motivation. The purpose of this design is to maximize success and minimize the sense of deprivation.
Third, leaderboards that reflect activities unrelated to learning performance should be designed to promote gamified learning. The goal of leaderboards is to encourage goal setting and engagement in learning activities. However, learners who are not interested in learning activities are not willing to engage in activities, no matter how much fun they are. This problem can be addressed by creating leaderboards for activities other than learning. For example, leaderboards for classroom tasks such as cleaning, counseling friends, library visits, and books borrowed from the library should be provided. Through leaderboards, participants can set a new and specific set of goals [29] and achieve success by moving up in the leaderboard ranks. In addition, activities other than learning can encourage frequent competition and easier point scoring. These features promote learning engagement, maximize success, and minimize a sense of deprivation.

**Design Principle 1: Leaderboards Should be Designed on Both Macro and Micro Levels**

Leaderboards frequently used in educational environments are macro leaderboards. In gamified learning environments, learner performance is incorporated into points or experience points that are shown on the leaderboard. Macro learning behavior is learning a theory named A in the gamified environment. The process of learning theory A is composed of microlevel learning behaviors such as A-1, A-2, and A-3 [30]. When using a macro leaderboard, it is possible to provide evaluation and feedback on macro learning behaviors but not on micro learning behaviors. It is therefore difficult to discern what activity a learner excels at from a macro leaderboard. This is because a macro leaderboard provides feedback on overall learning performance but does not give feedback on each learning activity. Kasworm and Blowers [31] suggested considering a variety of personal and environmental factors, as learners’ performance is the result of a combination of both factors. It is not easy for teachers to understand personal factors; however, environmental factors can be addressed by designers. If environmental factors are addressed, they can influence participants’ learning activities. Therefore, this study concludes that macro and micro leaderboards should be operated simultaneously. This provides learners with more experiences of success. Conversely, as the number of trials increases, the number of failures is expected to rise. Negative influences from increased failure should be controlled by gamification. If teachers can encourage learning activities through gamification [5], they can ensure more success than failure. Enhanced cooperation and more frequent competition between participants will create synergy for the achievement of individual goals [26,32].

**Design Principle 2: Integrate Each Measurable Element in the Gamified Learning Environment With a Micro Leaderboard**

In the same vein as Kasworm and Blowers [31], teachers who design gamified learning environments should integrate all elements into micro leaderboards. These elements include demographic factors. In learning environments, students are given grades based on their performance during a semester. Various evaluation items—from team activities to final exams—are designed to calculate grades. However, it is difficult for learners to obtain proper feedback because the items displayed on the leaderboard are only representative of activities or points that incorporate all activities. If a leaderboard is designed to incorporate each measurement applied in a gaming environment, learners will attempt to reach the upper ranking of that specific leaderboard. In the macro leaderboard, the greater the gap between the upper and lower ranks, the lower is the satisfaction with learning [33]. Meanwhile, learners’ confidence and learning activities are positively influenced by those in lower ranks relative to themselves [34]. As learners participate in more leaderboards where they compete with other learners in terms of performance, they gain confidence and are stimulated to try harder to earn high points. It is also important to provide multiple micro leaderboards to expose learners to objective evaluation and the achievements and competence of their peers. Using leaderboards facilitates the comparison of learning performance [35]. For example, if gamification is applied to a class during a semester and team activity scores, task scores, test scores, and badge acquisition status are elements applied to the leaderboard, other elements such as attendance points, the rankings of specific earned badges gained, the number of questions asked, the number of presentations, and other learning activities should be integrated into micro leaderboards. In the case of a web-based learning platform, all activities related to learning such as the time spent learning, the number of badges earned, or the number of assignments submitted (points) should be integrated with offline learning environment elements. Moreover, if the gender and age of the learner can be checked, leaderboards should be designed according to these factors. Actual web-based games provide a leaderboard based on most elements of the game such as server (region), occupation, and the gender of the game character.

**Design Principle 3: Leaderboards Should Incorporate Activities Other Than Learning**

The social characteristics of leaderboards have a positive influence on the learning effect through synergy with other game mechanics [35]. Leaderboards that focus on learning effects are effective for learners who rank highly; however, they can cause stress to newcomers or those who rank lower [27]. As a result, participants may have a negative perception of leaderboards. To encourage these disillusioned learners to focus on leaderboards again, a different approach is required. This requires a strategy to induce participants to engage in full-scale learning activities after eliminating the negative perceptions of leaderboards. This is done by introducing nonlearning activities. The leaderboard provides learners with their roles, responsibilities, and feedback on their status. [36]. The leaderboard causes participants to consider the influence of the leaderboard on other participants for activities other than learning. Nonlearning activities can weaken the sense of inadequacy caused by the leaderboard. Additionally, it will become easier for the participant to rank higher on the leaderboard for nonlearning activities than it is for learning-related leaderboards. Participants can maximize their success and find a state of flow through the process. At the same time, the needs of the participants in the mid and lower ranks will be met to minimize the sense of deprivation. Zhao and Tang
[37] conducted an analysis of gamification cases currently in service based on the 8 core drives of octalysis [9]. They showed that one of the sources of motivational affordance was scarcity. Scarcity is explained as the core driver of wanting something simply because it is unattainable. The less scarce the user perceives an object or activity, the more patient the user becomes. Lower-ranked learners may have already given up learning. However, if they experience a higher ranking on nonlearning leaderboards, they may develop a different perspective on learning leaderboards. Therefore, designing micro leaderboards gives participants new learning experiences and motivates them to achieve higher rankings on learning leaderboards.

Analysis of Leaderboard Cases Using the 3 Design Principles

Figure 5 [38-45] shows the leaderboard cases collected for this research. We conducted a Google search to discover leaderboard cases. During our search for leaderboard cases, we aimed to find cases of educational gamification. During the leaderboard case collection stage, it was confirmed that the use of leaderboards in the sports field was frequent. Therefore, we expanded our search range to the sports field. The keywords used for our Google search were as follows: (1) leaderboard case(s), (2) gamified leaderboard case(s), (3) gamification leaderboard case(s), (4) leaderboard in sport, and (5) gamified leaderboard cases in sport. A total of 10 cases were collected and analyzed with the design principles developed in this study. The degree of application of each design principle is represented as ● (completely applied), ◣ (partially applied), and ○ (not applied) in Figure 5.

Duolingo, Khan Academy, Memrise, Science Level Up, and Sololearn are web-based learning platforms. Fitbit, NikePlus, Imgur’s Pokemon Go, and Reebok Crossfit’s “The Open” Challenge are cases related to health care. Pokemon Go is analyzed from the perspective of gamification because it is possible to monitor health through the game [46]. Teaching Above the Test is a leaderboard freely available through Google Sheets in gamified learning environments (Figure 6).
According to the analysis, the leaderboards on Reebok Crossfit’s “The Open,” Khan Academy, and Imgur’s Pokemon Go were found to be the most efficient. In contrast, Science Level Up’s leaderboard was the least efficient. Imgur’s Pokemon Go leaderboard lists all the badges obtainable in Pokemon Go and offers leaderboards according to region with relevant statistics. In addition, leaderboards are renewed in the form of monthly reports and published. The first leaderboard on the page is a macro leaderboard, and micro leaderboards are displayed by content underneath. Design principles 1, 2, and 3 have all been applied to this leaderboard. Figure 7 shows the leaderboard used in Reebok Crossfit’s “The Open” challenge. “The Open” is an event that has been ongoing since 2011. Anyone can participate and the event is held around the world simultaneously. The management designs a specific exercise as 1 set. Participants record 1 set during the period set by the management and the result is reflected on the leaderboard [47,48]. The main leaderboard webpage of “The Open” is a macro leaderboard. It shows the total points and ranks for each participant during the entire period. Users can set options to see micro leaderboards. This corresponds to principle 1 developed in this study. It is possible to see micro leaderboards by competition type (open, online qualifier, regionals, sectionals, games, team series, and liftoff), gender, and age group (divided into 5-year age groups from 10 years to 60 years), region, and year. This corresponds to principles 2 and 3 developed in this study. The strategies and physical competence of the players can be analyzed through the leaderboard. The Reebok Crossfit games webpage provides information on the types of exercises for each season. Based on the information, additional information about each player, such as his/her physical competence, characteristics, and strategies, can be obtained to compare with others who are ranked on the leaderboard. Thus, the exercises are designed to enable the leaderboard to be used from various perspectives and to provide the player with the ability to use the leaderboard as a means of improving performance.
Figure 8 shows the leaderboard of Khan Academy, which offers gamified programming learning content. The leaderboard provides micro leaderboards instead of a macro leaderboard. Leaderboards are provided for each of the elements identifiable as an indicator of learning activity in Khan Academy (challenge patches, energy points, video watching count, badge counts, streak stacks, answer counts, and project evaluation). This corresponds to principles 2 and 3 developed in this study. Web-based learning activities are presumed not to provide leaderboards reflecting precise gender and age groups. When users click on the identification of learners registered on the leaderboard, they can move to each player’s profile webpage to see detailed information. Khan Academy’s micro leaderboards reflect the number of badges acquired and social interactions such as the number of comments sent to other learners and programming training. This represents the principle 3 developed in this study. In contrast, Science Level Up was found to be the worst leaderboard. A macro leaderboard is not provided and micro boards are only offered by content. Additionally, only 1 micro leaderboard is provided for each content type, without differentiation by grade or demographic characteristics. None of the principles developed in this research are applied.
Figure 8. Leaderboard used in Reebok Crossfit’s “The Open” challenge.

Discussion

This study designed efficient leaderboards to motivate learners in gamified learning environments. Leaderboards are an efficient tool for competition and cooperation and can help learners set specific goals, boost learning motivation, and unleash affordances in the desired direction. However, as the gap between learners in terms of learning performance widens, learning motivation weakens. This study analyzed the negative influence of leaderboards on participants through a literature review and set the following 4 objectives for the design principles.

1. Objective 1: Minimize the sense of inadequacy.
2. Objective 2: Minimize learners’ experience of failure to minimize downward counterfactual thinking.
3. Objective 3: Maximize learners’ experience of success to induce upward counterfactual thinking.
4. Objective 4: Design leaderboards that measure learning performance to induce learners to obtain high scores and compete with each other frequently.

This study expects the following 3 leaderboard design principles to minimize the negative influence of leaderboards on participants and to improve leaderboard effectiveness. The design principles are as follows:

1. Design principle 1: Macro leaderboard and micro leaderboards should be designed and operated together.
2. Design principle 2: All the elements used to measure learners’ achievements in an educational environment should be incorporated into micro leaderboards.
3. Design principle 3: A “geeks leaderboard,” a type of micro leaderboard for activities other than learning, should be designed.

The negative influence of leaderboards should be controlled by gamification and teachers should promote affordances to guide learners in the right direction. Among game mechanics, leaderboards that encourage competition and cooperation based on social competence provide direct feedback to learners. Leaderboards should be designed and operated following appropriate design standards. Efficient leaderboard design principles are suggested in this study based on a literature review. In offline classrooms, a few instructors must control many learners and there are many items to manage. However, the introduction of gamification facilitates efficient classroom operation. There are cases of gamification that assist classroom operations such as class craft and class dojo. If leaderboards are designed and operated according to the leaderboard design principles suggested in this research, learning satisfaction and performance are expected to improve. When using leaderboards in web-based learning platforms as well as offline classrooms, this study recommends applying the principles developed in this study. Learners who experience leaderboards in other web-based environments perceive them as content rather than as a tool for competition or ranking [49]. Motivational affordances can be promoted through leaderboards unlike points or levels [50]. Individuals who have experienced leaderboards in other domains accept the competitive environment of the leaderboard in an educational context. We expect that this dynamic will motivate learners more naturally than other game mechanics. Thus, this study suggests that the leaderboard design...
principles developed here will enhance web-based gamified learning environments. Designers should refer to Reebok Crossfit’s “The Open” Challenge, Khan Academy, and Imgur’s Pokemon Go leaderboard.

This research has the following limitations. The suggested leaderboard design principles should be applied in education contexts and be verified for effectiveness. Basic leaderboard designs use leaderboards provided by the gamification system or formats shared on the internet. However, gamified leaderboards do not always produce positive effects. Therefore, the leaderboard design principles suggested in this research should be applied to leaderboard design and their effectiveness should be verified by learners. Glynn et al [51] developed the science motivation questionnaire 2 with reliability and validity guaranteed by statistical validation. The questionnaire is composed of intrinsic motivation, career motivation, self-determination, self-efficacy, and grade motivation factors. Future studies should design leaderboards following the leaderboard design principles developed in this study and use the survey tool to analyze the efficiency of the leaderboard design principles of this study in the education field. Furthermore, the leaderboards for use in other fields can be designed based on the results of this study, and the possibility of field expansion will be suggested through future studies.

Acknowledgments
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Conflicts of Interest
None declared.

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Leisure and Problem Gaming Behaviors Among Children and Adolescents During School Closures Caused by COVID-19 in Hong Kong: Quantitative Cross-sectional Survey Study

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Abstract

Background: School closures during the COVID-19 pandemic may have exacerbated students’ loneliness, addictive gaming behaviors, and poor mental health. These mental health issues confronting young people are of public concern.

Objective: This study aimed to examine the associations between loneliness and gaming addiction behaviors among young people in Hong Kong and to investigate how familial factors, psychological distress, and gender differences moderate these relationships.

Methods: This cross-sectional study was conducted in June 2020 when schools reopened after 6 months of school closures. Participants included 2863 children and adolescents in primary (Grades 4 to 6) and secondary (Grades 7 and 8) schools (female participants: 1502/2863, 52.5%). Chi-square tests, one-way analyses of variance, and independent-samples t tests were performed to compare the differences of distribution in gaming addiction behaviors across gender, age, and other sociodemographic characteristics. Multinomial logistic regression analyses were conducted to identify factors that relate to excessive or pathological gaming behaviors separately, in comparison with leisure gaming.

Results: A total of 83.0% (2377/2863) of the participants played video games during the COVID-19 pandemic. The prevalence of excessive and pathological game addiction behaviors was 20.9% (597/2863) and 5.3% (153/2863), respectively. More male students had gaming addiction symptoms than female students. The multinomial logistic regressions showed that feeling lonely was associated with more problematic gaming behaviors, and the association was stronger for older female students. Low socioeconomic status, less parental support and less supervision, and poor mental health were risk factors for gaming addiction behaviors, especially among primary school students.

Conclusions: Loneliness was associated with gaming addiction behaviors; the findings from this study suggested that this association was similar across gender and age groups among young people. Familial support and supervision during school closures can protect young people from developing problematic gaming behaviors. Results of this study have implications for prevention and early intervention on behalf of policy makers and game developers.

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KEYWORDS
COVID-19; leisure gaming; excessive gaming; pathological gaming; familial factors; loneliness; COVID-19 lockdown; school closure

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Introduction

It is estimated that over 80% of adolescents play video games [1,2]. The prevalence of gaming disorders among adolescents is estimated to be between 1.3% and 19.9% [3], with 8.1% to 10.6% of them involved in excessive gaming and 2.3% to 2.7% involved in pathological gaming [4,5]. Young people are more likely to get involved in pathological gaming than people in other age groups [6]. Social distancing and daily routine changes due to the COVID-19 pandemic may have intensified young people’s gaming behaviors. Gaming disorders were found to be associated with poor academic performance [7,8], loneliness [9-11], and a number of health and mental health issues.

Problem gaming behaviors among physically and socially isolated young people during school closures under the pandemic have drawn the concerns of policy makers, researchers, and helping professionals. Elevated loneliness may lead to depression and suicidal ideation, and the chronic impact may last even after the pandemic. According to the self-determination theory, playing video games may provide a sense of autonomy, competence, and relatedness for most people [12]; however, uncontrolled excessive gaming may lead to gaming disorders. Notably, the linear relationship between loneliness and gaming addiction is debatable. Some studies have suggested that problem gaming behaviors were not associated with loneliness [13,14], while others provided support for their association [15-20]. Moreover, gender differences in gaming disorders, with more males having them [3,21], and inconsistent gender differences in perceived loneliness [22-24] have been observed in previous studies. Yet, few studies have examined whether there are sex differences in the association of game addiction with loneliness. As young people stay at home longer during school closures caused by COVID-19, family structure, socioeconomic status (SES) [25-28], and parenting characteristics (ie, parental support and supervision) [29,30] play a strong role in the impact of gaming behaviors on young people’s well-being and development. It is clear from the above literature that the association between gaming disorders and a sense of loneliness among young people remains uncertain.

To fill the void, this study aims to examine the prevalence of gaming behaviors during the school closure period in Hong Kong and identify factors that contribute to the association between gaming behaviors and loneliness among young people. We hypothesized that young people who were lonelier during the isolation period were more likely to be addicted to gaming and that there were age and gender differences after adjustment by familial and mental health factors.

Methods

Data Collection and Sample

This study adopted a cross-sectional survey design with a questionnaire that adopted a variety of validated scales from previous studies. Ethical approvals were granted by the Human Subjects Ethics Sub-Committee of the Hong Kong Polytechnic University (No. HSEARS20161222006). This study drew a stratified random sample of adolescent students from four primary schools and 13 secondary schools in Hong Kong. Students in all classes from grades 4 to 6 in primary schools and grades 7 to 8 in secondary schools were approached with an invitation letter detailing the research objectives and possible risks and benefits of participation. Parental consent was obtained and each respondent gave formal consent for his or her participation in the study by signing a consent form. We aimed to have a sample that could yield a margin of error of 0.98/√n = 1.8%. In total, 4635 students and their parents were approached and 2863 students filled in the survey, giving a response rate of 61.8%. Students completed the questionnaires in class in the presence of the research assistant and received souvenirs (worth about US $5) after the completion of the survey.

Measures

Gaming Addiction

Gaming behavior was measured using the Chinese children’s version of the 7-item Game Addiction Scale (GAS) [4,31]. The GAS was conceptually developed based on the criteria for pathological gaming in the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition). Some items were adapted for young adolescents (eg, “I played a game to forget my real life” was changed to “I have played games and missed planned work”) [31]. Responses were measured on a 6-point Likert scale, with scores ranging from 1 (strongly disagree) to 6 (strongly agree); scores of 4 (slightly agree) to 6 (strongly agree) were taken as endorsement of the described addiction symptom. Endorsement of zero to three items was categorized as leisure gaming, endorsement of four to six items was categorized as excessive gaming, and endorsement of seven items was categorized as pathological gaming [32]. The internal consistency of this scale, as measured by Cronbach α, is .87.

Gaming Time and Mode

Participants were asked to report their average hours (ie, none, half hour, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, and more than 5 hours) spent playing video games each day during school closures. Participants were also asked whether their main mode of electronic gaming was multiplayer or single player [8] and to report their most-used device for gaming: (1) smartphone, tablet, or iPad; (2) computer; or (3) other.

Loneliness

Loneliness was measured by a single-item question: “How often do you feel lonely?” [33]. Responses were based on frequency and ranged from 0 (not at all) to 3 (nearly every day). This is a commonly used, single self-reporting format to measure loneliness in academic research studies [34]. This short question regarding loneliness was asked directly and made it easy to administer and score [35]. Higher scores indicated greater loneliness.

Parental Support

Parental support was measured using the 4-item family subscale of the Multidimensional Scale of Perceived Social Support (MSPSS) [36]. The word “family” in the original MSPSS was replaced with the word “parents” to assess the social support from parents only. An example item was “My parent is willing...
to help me make decisions.” Students responded using a 6-point Likert scale, ranging from 1 (strongly disagree) to 6 (strongly agree). Higher scores indicated higher levels of parental support. The internal consistency of this scale, as measured by Cronbach α, is .91.

**Parental Supervision**

Parental supervision was measured by three items: (1) “My parents know what I do after school,” (2) “My parents know how I spend my pocket money,” and (3) “My parents know how I spend my free time.” These items were adapted from the Parental Monitoring Scale [37]. Students responded using a 6-point Likert scale, ranging from 1 (strongly disagree) to 6 (strongly agree). Higher scores represented higher levels of parental supervision. The internal consistency of this scale, as measured by Cronbach α, is .81.

**Depression**

Depression was measured using the Patient Health Questionnaire-9 [38,39]. It consists of nine items for assessing depression symptoms in the past 2 weeks (eg, little interest or pleasure in doing things). Response options, with respect to frequency, range from 0 (not at all) to 3 (nearly every day). Higher scores represent more depressive symptoms. The internal consistency of this scale, as measured by Cronbach α, is .85.

**Anxiety**

Anxiety was measured using the Generalized Anxiety Disorder-7 scale [40,41], which is a popular tool that screens for, and measures the severity of, generalized anxiety disorder. It consists of seven items that assess general anxiety symptoms in the past 2 weeks (eg, not being able to stop or control worrying). Response options, with respect to frequency, range from 0 (not at all) to 3 (nearly every day). Higher scores represent more anxiety symptoms. The internal consistency of this scale, as measured by Cronbach α, is .92.

**Sociodemographic Characteristics**

Information collected on the sociodemographic characteristics of the participants included gender, age, grade, family structure (ie, living with both parents, living with father or mother, or living with no parent), and SES. SES was measured by collecting information about parental education, parents having a paid job or not, the number of household appliances, the number of e-learning devices, home internet accessibility, and the family having a car or not. These questions were more tangible for young children to answer in order to collect SES information [42]. Household appliances included televisions, refrigerators, microwaves, laundry washing machines, dishwashers, air conditioners, and audio-visual equipment [43]. The number of household appliances was summed up and this indicator ranged from 1 to 7. E-learning devices included desktop computers, notebook computers, iPads or other tablets, smartphones, and e-book readers. The number of devices was summed up and this indicator ranged from 1 to 5. Home internet accessibility was measured by a single-item question: “Are internet conditions at home satisfying your needs in your daily lives and in learning?”; responses ranged from 0 to 4 [44-46]. Possible responses regarding car ownership by the student’s family were 0 (no) and 1 (yes). The four variables above reflected participants’ SES; higher values indicated higher family SES.

**Data Analysis**

Data were entered into SPSS Statistics software, version 24 (IBM Corp), for analyses. First, the correlations and reliabilities for major variables were established. Second, frequencies and proportions for categorical variables or mean and standard deviation for continuous variables were used to describe the characteristics of the participants and to describe excessive or pathological gaming addiction among the participants by different characteristics. Third, chi-square tests, one-way analyses of variance, and independent-samples t tests were used to compare the differences of distribution in gaming addictions between genders, age groups (ie, primary or secondary school students), and other sociodemographic characteristics. Missing data were handled by multiple imputation, imputing 10 sets of complete data sets with 25 iterations per imputation. Fourth, multinomial logistic regression analyses were conducted to estimate the odds ratios (ORs) with 95% CIs of different characteristics for participants engaged in excessive or pathological gaming separately from leisure gaming; different levels of adjustment were controlled to examine the robustness of the associations. In the crude model, we examined the association between loneliness and gaming. In Model 1, we included age and gender (ie, male or female). In Model 2, we included family and parental factors of participants, including family structure (ie, living with no parent, living with father or mother, and living with both parents), father’s job status (ie, with or without a paid job), mother’s job status (ie, with or without a paid job), household appliances, e-learning devices, home internet accessibility, parental support, and parental supervision. In Model 3, we additionally adjusted for covariates of students’ mental health: depression and anxiety. We conducted subgroup analyses to examine whether the associations of gaming addiction with loneliness were different among primary school students and secondary school students.

Two subgroup analyses were conducted to examine whether the associations of gaming addiction with loneliness differed by gender and were conducted by three-step multinomial logistic regressions. The regression analyses for the age subgroups were similar to the full sample analysis. In the gender subgroup analyses in the crude model, we examined the association between loneliness and gaming. In Model 1, we adjusted for family and parental factors of participants, including age, family structure, father’s job status, mother’s job status, household appliances, e-learning devices, home internet accessibility, parental support, and parental supervision. In Model 2, we additionally adjusted for covariates of students’ mental health: depression and anxiety.

Multiple imputation was used to minimize the impact of missing data of the sociodemographic factors. These factors were father’s and mother’s educational level and father’s and mother’s job status, which had more than 25% missing data due to children indicating they did not know the answers. A total of 10 imputations were generated. The pooled standardized regression
coefficients were calculated across the 10-imputation data sets [47].

Results

Overview
Among the 2863 students participating in this study, 181 (6.3%) were in Grade 4, 208 (7.3%) were in Grade 5, 210 (7.3%) were in Grade 6, 1209 (42.2%) were in Grade 7, and 1055 (36.8%) were in Grade 8. The participants’ ages ranged from 8 to 17 years (mean 12.6, SD 1.32). The gender ratio of the participants was close to 1:1 (male: 1346/2848, 47.3%). Most participants lived with both parents (2282/2818, 81.0%), and a small proportion of them lived with either their father (109/2818, 3.9%) or their mother (324/2818, 11.5%). Their parents’ educational levels were primary school level (father: 112/1723, 6.5%; mother: 122/1766, 6.9%), middle school level (father: 1034/1723, 60.0%; mother: 1075/1766, 60.9%), and university level or above (father: 577/1723, 33.5%; mother: 569/1766, 32.2%). Many students did not know their parents’ educational levels and/or did not answer the questions (1140/2863, 39.8% missing data regarding father’s educational level; 1097/2863, 38.3% missing data regarding mother’s educational level). Around half of their parents had a paid job (father: 1905/2037, 93.5%; mother: 1429/2088, 68.4%); many students did not know their parents’ job statuses and did not answer the questions (826/2863, 28.9% missing data regarding father’s job status; 775/2863, 27.1% missing data regarding mother’s job status). A total of 693 participants out of 2541 (27.3%) indicated that their family had a car. The mean numbers of household appliances and e-learning devices were 4.80 (SD 1.48) and 2.57 (SD 1.00), respectively. The mean response score given by participants for satisfactory home internet access was 3.04 (SD 0.93).

The Gaming Behaviors of Children and Adolescents
A majority of students in the study (2377/2863, 83.0%) admitted that they played video games every day during the school closure period for 30 minutes (305/2863, 10.7%), 1 hour (340/2863, 11.9%), 2 hours (451/2863, 15.8%), 3 hours (516/2863, 18.0%), 4 hours (376/2863, 13.1%), 5 hours (258/2863, 9.0%), and for more than 5 hours (131/2863, 4.6%). Most of them (1927/2863, 67.3%) were involved in multiplayer games while the rest (582/2863, 20.3%) played individually. Many of them used smartphones, tablets, or iPads (1996/2863, 69.7%); computers (274/2863, 9.6%); and other devices (108/2863, 3.8%) for game playing.

The findings of the GAS are shown in Table 1. In this study, 266 participants out of 2863 (9.3%) reported that they did not play any games during the school closure period, whereas 1432 students (55.2%) reported to have played games longer than intended. The most frequently reported gaming addiction symptom was tolerance (1432/2595, 55.2%), which was followed by preoccupation (1189/2597, 45.8%), escape (913/2587, 35.3%), and unsuccessful attempts to stop or reduce playing (885/2588, 34.2%). Male participants were more likely to report gaming addiction symptoms than their female counterparts, except on the third item, “I have played games and missed planned work.”

Overall, 2518 out of 2863 (87.9%) participants reported having at least one gaming addiction symptom, with 1768 (61.8%) students playing games as a leisure activity (1 to 3 symptoms), 597 (20.9%) students reporting excessive gaming addiction behaviors (4 to 6 symptoms), and 153 (5.3%) students reporting pathological gaming behaviors (7 symptoms) (Table 2; for more detailed information about participant characteristics, see Table S1 in Multimedia Appendix 1). Male students showed a significantly higher prevalence of excessive gaming and pathological gaming behaviors than females, while more females reported no gaming behaviors ($\chi^2=103.1; P<.001$). Primary school students showed a significantly higher prevalence of excessive gaming behaviors than secondary school students. Secondary school students showed a significantly higher prevalence of pathological gaming behaviors than primary school students ($\chi^2=8.5; P=.04$). Those who reported excessive gaming behaviors were significantly younger than those who reported leisure and pathological gaming behaviors ($F=4.03; P=.007$).

With respect to the influence of familial and mental health factors, students reporting pathological gaming behaviors had lower home internet access rates, less parental support and supervision, and higher loneliness, depression, and anxiety levels than students reporting leisure and excessive gaming behaviors (all had P values <.05).
<table>
<thead>
<tr>
<th>Statement</th>
<th>Gave valid response (N=2863), n (%)</th>
<th>Disagree(^b), n (%)</th>
<th>Agree(^c), n (%)</th>
<th>DSM-5 criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I have thought all day long about playing a game.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All participants</td>
<td>2597 (90.7)</td>
<td>1408 (54.2)</td>
<td>1189 (45.8)</td>
<td>Preoccupation</td>
</tr>
<tr>
<td>Male</td>
<td>1314/2583 (50.9)</td>
<td>620 (47.2)</td>
<td>694 (52.8)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1269/2583 (49.1)</td>
<td>783 (61.7)</td>
<td>486 (38.3)</td>
<td></td>
</tr>
<tr>
<td><strong>I have played longer than intended.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All participants</td>
<td>2595 (90.6)</td>
<td>1163 (44.8)</td>
<td>1432 (55.2)</td>
<td>Tolerance</td>
</tr>
<tr>
<td>Male</td>
<td>1313/2581 (50.9)</td>
<td>547 (41.7)</td>
<td>766 (58.3)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1268/2581 (49.1)</td>
<td>612 (48.3)</td>
<td>656 (51.7)</td>
<td></td>
</tr>
<tr>
<td><strong>I have played games and missed planned work.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All participants</td>
<td>2587 (90.4)</td>
<td>1674 (64.7)</td>
<td>913 (35.3)</td>
<td>Escape</td>
</tr>
<tr>
<td>Male</td>
<td>1306/2573 (50.8)</td>
<td>848 (64.9)</td>
<td>458 (35.1)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1267/2573 (49.2)</td>
<td>820 (64.7)</td>
<td>447 (35.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Others have unsuccessfully tried to reduce my time spent on games.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All participants</td>
<td>2588 (90.4)</td>
<td>1703 (65.8)</td>
<td>885 (34.2)</td>
<td>Unsuccessful attempts to stop or reduce playing</td>
</tr>
<tr>
<td>Male</td>
<td>1307/2574 (50.8)</td>
<td>823 (63.0)</td>
<td>484 (37.0)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1267/2574 (49.2)</td>
<td>870 (68.7)</td>
<td>397 (31.3)</td>
<td></td>
</tr>
<tr>
<td><strong>I have felt upset when I was unable to play.</strong></td>
<td></td>
<td></td>
<td></td>
<td>Withdrawal</td>
</tr>
<tr>
<td>All participants</td>
<td>2586 (90.3)</td>
<td>1976 (76.4)</td>
<td>610 (23.6)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1304/2573 (50.7)</td>
<td>911 (69.9)</td>
<td>393 (30.1)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1269/2573 (49.3)</td>
<td>1055 (83.1)</td>
<td>214 (16.9)</td>
<td></td>
</tr>
<tr>
<td><strong>I have had arguments with others (eg, family and friends) over my time spent on games.</strong></td>
<td></td>
<td></td>
<td></td>
<td>Deceiving others</td>
</tr>
<tr>
<td>All participants</td>
<td>2575 (89.9)</td>
<td>1913 (74.3)</td>
<td>662 (25.7)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1303/2561 (50.9)</td>
<td>896 (68.8)</td>
<td>407 (31.2)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1258/2561 (49.1)</td>
<td>1006 (80.0)</td>
<td>252 (20.0)</td>
<td></td>
</tr>
<tr>
<td><strong>I have neglected important activities (eg, school, work, and sports) to play games.</strong></td>
<td></td>
<td></td>
<td></td>
<td>Loss of interest</td>
</tr>
<tr>
<td>All participants</td>
<td>2583 (90.2)</td>
<td>1958 (75.8)</td>
<td>625 (24.2)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1304/2569 (50.8)</td>
<td>975 (74.8)</td>
<td>329 (25.2)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1265/2569 (49.2)</td>
<td>972 (76.8)</td>
<td>293 (23.2)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) DSM-5: Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition.

\(^b\) Answers of disagree were taken to mean there were no addiction symptoms.

\(^c\) Answers of agree were taken to mean there were addiction symptoms.
Table 2. Participant characteristics in different gaming groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gaming behavior (N=2863)</th>
<th>Overall</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Leisure</td>
<td>Excessive</td>
</tr>
<tr>
<td><strong>Gender$^a$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (n=1346)</td>
<td>85 (6.3)</td>
<td>833 (61.9)</td>
<td>332 (24.7)</td>
</tr>
<tr>
<td>Female (n=1502)</td>
<td>258 (17.2)</td>
<td>927 (61.7)</td>
<td>261 (17.4)</td>
</tr>
<tr>
<td>Total (n=2848)</td>
<td>343 (12.0)</td>
<td>1760 (61.8)</td>
<td>593 (20.8)</td>
</tr>
<tr>
<td><strong>School group$^a$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary (n=599)</td>
<td>62 (10.4)</td>
<td>368 (61.4)</td>
<td>145 (24.2)</td>
</tr>
<tr>
<td>Secondary (n=2264)</td>
<td>283 (12.5)</td>
<td>1400 (61.8)</td>
<td>452 (20.0)</td>
</tr>
<tr>
<td>Total (N=2863)</td>
<td>345 (12.1)</td>
<td>1768 (61.8)</td>
<td>597 (20.9)</td>
</tr>
<tr>
<td><strong>Live with parent$^a$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both parents (n=2282)</td>
<td>283 (12.4)</td>
<td>1436 (62.9)</td>
<td>457 (20.0)</td>
</tr>
<tr>
<td>Father (n=109)</td>
<td>7 (6.4)</td>
<td>62 (56.9)</td>
<td>30 (27.5)</td>
</tr>
<tr>
<td>Mother (n=324)</td>
<td>38 (11.7)</td>
<td>180 (55.6)</td>
<td>77 (23.8)</td>
</tr>
<tr>
<td>Neither parent (n=103)</td>
<td>11 (10.7)</td>
<td>70 (68.0)</td>
<td>18 (17.5)</td>
</tr>
<tr>
<td>Total (n=2818)</td>
<td>339 (12.0)</td>
<td>1748 (62.0)</td>
<td>582 (20.7)</td>
</tr>
<tr>
<td><strong>Father’s education level$^b$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary school (n=112)</td>
<td>13 (11.6)</td>
<td>67 (59.8)</td>
<td>24 (21.4)</td>
</tr>
<tr>
<td>Middle school (n=1034)</td>
<td>106 (10.3)</td>
<td>652 (63.1)</td>
<td>221 (21.4)</td>
</tr>
<tr>
<td>University or above (n=577)</td>
<td>114 (19.8)</td>
<td>358 (62.0)</td>
<td>83 (14.4)</td>
</tr>
<tr>
<td>Total (n=1723)</td>
<td>233 (13.5)</td>
<td>1077 (62.5)</td>
<td>328 (19.0)</td>
</tr>
<tr>
<td><strong>Mother’s education level$^b$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary school (n=122)</td>
<td>17 (13.9)</td>
<td>71 (58.2)</td>
<td>27 (22.1)</td>
</tr>
<tr>
<td>Middle school (n=1075)</td>
<td>124 (11.5)</td>
<td>658 (61.2)</td>
<td>229 (21.3)</td>
</tr>
<tr>
<td>University or above (n=569)</td>
<td>93 (16.3)</td>
<td>379 (66.6)</td>
<td>75 (13.2)</td>
</tr>
<tr>
<td>Total (n=1766)</td>
<td>234 (13.3)</td>
<td>1108 (62.7)</td>
<td>331 (18.7)</td>
</tr>
<tr>
<td><strong>Father has a paid job$^b$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No (n=132)</td>
<td>17 (12.9)</td>
<td>75 (56.8)</td>
<td>31 (23.5)</td>
</tr>
<tr>
<td>Yes (n=1905)</td>
<td>238 (12.5)</td>
<td>1207 (63.4)</td>
<td>379 (19.9)</td>
</tr>
<tr>
<td>Total (n=2037)</td>
<td>255 (12.5)</td>
<td>1282 (62.9)</td>
<td>410 (20.1)</td>
</tr>
<tr>
<td><strong>Mother has a paid job$^b$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No (n=659)</td>
<td>98 (14.9)</td>
<td>397 (60.2)</td>
<td>135 (20.5)</td>
</tr>
<tr>
<td>Yes (n=1429)</td>
<td>170 (11.9)</td>
<td>905 (63.3)</td>
<td>286 (20.0)</td>
</tr>
<tr>
<td>Total (n=2088)</td>
<td>268 (12.8)</td>
<td>1302 (62.4)</td>
<td>421 (20.2)</td>
</tr>
<tr>
<td><strong>Family owns a car$^a$, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No (n=1848)</td>
<td>240 (13.0)</td>
<td>1128 (61.0)</td>
<td>391 (21.2)</td>
</tr>
<tr>
<td>Yes (n=693)</td>
<td>81 (11.7)</td>
<td>446 (64.4)</td>
<td>131 (18.9)</td>
</tr>
<tr>
<td>Total (n=2541)</td>
<td>321 (12.6)</td>
<td>1574 (61.9)</td>
<td>522 (20.5)</td>
</tr>
<tr>
<td><strong>Number of household appliances$^b$, mean (SD)</strong></td>
<td>4.90 (1.34)</td>
<td>4.82 (1.48)</td>
<td>4.71 (1.51)</td>
</tr>
<tr>
<td><strong>Number of e-learning devices$^b$, mean (SD)</strong></td>
<td>2.60 (1.00)</td>
<td>2.64 (1.01)</td>
<td>2.43 (0.93)</td>
</tr>
</tbody>
</table>
## Loneliness and Gaming Addiction

In the previous 2 weeks, 176 out of 2863 participants (6.1%) felt lonely almost every day, 206 participants (7.2%) felt lonely nearly half of the days, and 538 participants (18.8%) felt lonely several days. Among those who reported loneliness, 58.4% (536/918) were females ($\chi^2 = 21.4$; $P < .001$). A significant difference was found between genders ($t_{2842} = 4.40$; $P < .001$) but not between age groups.

Loneliness was positively associated with both excessive and pathological gaming behaviors. After adjusting for age and gender, the adjusted ORs (aORs) of loneliness increased to 1.23 (95% CI 1.19-1.26) and 1.45 (95% CI 1.38-1.53), respectively, for excessive (Table 3) and pathological gaming behaviors (Table 4). Compared to leisure gaming, being lonely increased the likelihood of excessive and pathological gaming behaviors by 23% and 45%, respectively. The aORs did not change substantially from Model 1 to Model 2, which adjusted for parenting. However, after adjusting for depression and anxiety variables, the aORs of loneliness decreased substantially, from 1.19 (95% CI 1.15-1.23) to 0.91 (95% CI 0.87-0.95) for excessive gaming behaviors and from 1.39 (95% CI 1.33-1.47) to 0.89 (95% CI 0.82-0.96) for pathological gaming behaviors. Significant associations between loneliness and gaming disorders were also found across different age and sex groups (Tables S2-S5 in Multimedia Appendix 1). Generally, being lonely was associated with a higher risk of excessive and pathological gaming behaviors, except for primary school students where there was a higher risk of excessive gaming behaviors. The magnitude of the association was relatively higher for pathological gaming behaviors, especially for girls and primary school students.

### Table 2: Correlation of Game Addiction with Different Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>None</th>
<th>Leisure</th>
<th>Excessive</th>
<th>Pathological</th>
<th>Overall</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home internet access satisfaction score $^b$, mean (SD)</td>
<td>3.05 (0.99)</td>
<td>3.10 (0.89)</td>
<td>2.93 (0.97)</td>
<td>2.76 (1.01)</td>
<td>3.04 (0.93)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age (years)$^b$, mean (SD)</td>
<td>12.64 (1.31)</td>
<td>12.63 (1.30)</td>
<td>12.45 (1.39)</td>
<td>12.78 (1.23)</td>
<td>12.61 (1.32)</td>
<td>.01</td>
</tr>
<tr>
<td>Parental support (MSPSS$^c$ family subscale score)$^b$, mean (SD)</td>
<td>4.00 (1.20)</td>
<td>3.94 (1.27)</td>
<td>3.79 (1.20)</td>
<td>3.63 (1.13)</td>
<td>3.90 (1.24)</td>
<td>.002</td>
</tr>
<tr>
<td>Parental supervision score $^b$, mean (SD)</td>
<td>4.36 (1.23)</td>
<td>4.22 (1.25)</td>
<td>4.09 (1.24)</td>
<td>3.87 (1.12)</td>
<td>4.19 (1.24)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Loneliness score $^b$, mean (SD)</td>
<td>0.53 (0.92)</td>
<td>0.47 (0.84)</td>
<td>0.60 (0.88)</td>
<td>0.75 (1.07)</td>
<td>0.52 (0.87)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Depression (PHQ-9$^d$ score)$^b$, mean (SD)</td>
<td>5.52 (5.19)</td>
<td>4.75 (4.84)</td>
<td>6.73 (5.29)</td>
<td>8.63 (6.51)</td>
<td>5.44 (5.18)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Anxiety (GAD-7$^e$ scale score)$^b$, mean (SD)</td>
<td>4.18 (4.81)</td>
<td>3.38 (4.66)</td>
<td>4.76 (5.16)</td>
<td>6.15 (6.29)</td>
<td>3.91 (4.94)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

$^a$Chi-square tests were performed to compare differences in game addiction with respect to different characteristics.

$^b$One-way analyses of variance were performed to compare differences in game addiction with respect to different characteristics.

$^c$MSPSS: Multidimensional Scale of Perceived Social Support.

$^d$PHQ-9: Patient Health Questionnaire-9.

$^e$GAD-7: Generalized Anxiety Disorder-7.
Table 3. Multinomial logistic regression of excessive gaming addiction (N=2863).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio (95% CI)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crude model(^b)</td>
</tr>
<tr>
<td>Loneliness</td>
<td>1.19*** (1.15-1.23)</td>
</tr>
<tr>
<td>Age</td>
<td>N/A(^f)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>N/A</td>
</tr>
<tr>
<td>Female</td>
<td>N/A</td>
</tr>
<tr>
<td>Live with parent</td>
<td></td>
</tr>
<tr>
<td>Neither parent</td>
<td>N/A</td>
</tr>
<tr>
<td>Either father or mother</td>
<td>N/A</td>
</tr>
<tr>
<td>Both father and mother</td>
<td>N/A</td>
</tr>
<tr>
<td>Father has a paid job</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Mother has a paid job</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Household appliances</td>
<td>N/A</td>
</tr>
<tr>
<td>e-Learning devices</td>
<td>N/A</td>
</tr>
<tr>
<td>Home internet access</td>
<td>N/A</td>
</tr>
<tr>
<td>Parental support</td>
<td>N/A</td>
</tr>
<tr>
<td>Parental supervision</td>
<td>N/A</td>
</tr>
<tr>
<td>Depression</td>
<td>N/A</td>
</tr>
<tr>
<td>Anxiety</td>
<td>N/A</td>
</tr>
</tbody>
</table>

\(^a\)The odds ratios and 95% CIs for excessive and pathological gaming addiction behaviors were calculated separately, with leisure gaming as the reference sample.

\(^b\)In the crude model, we examined the association between loneliness (continual) and gaming.

\(^c\)In Model 1, we additionally adjusted for age and gender.

\(^d\)In Model 2, we additionally adjusted for family structure, the father's job status, the mother's job status, household appliances (continual), e-learning devices (continual), home internet access (continual), parental support (continual), and parental supervision (continual).

\(^e\)In Model 3, we additionally adjusted for depression (continual) and anxiety (continual).

\(^f\)N/A: not applicable; this variable was adjusted for in subsequent models.

**P<.01.

***P<.001.
## Table 4. Multinomial logistic regression of pathological gaming addiction (N=2863).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio (95% CI)a</th>
<th>Crude modelb</th>
<th>Model 1c</th>
<th>Model 2d</th>
<th>Model 3e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loneliness</td>
<td>1.39*** (1.33-1.47)</td>
<td>1.45*** (1.38-1.53)</td>
<td>1.35*** (1.28-1.43)</td>
<td>0.89** (0.82-0.96)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>N/Af</td>
<td>1.07*** (1.04-1.11)</td>
<td>1.07*** (1.03-1.11)</td>
<td>1.04 (1.00-1.08)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>N/A</td>
<td>2.09*** (1.88-2.32)</td>
<td>1.90*** (1.71-2.12)</td>
<td>2.37*** (2.09-2.69)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>N/A</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>Live with parent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither parent</td>
<td>N/A</td>
<td>N/A</td>
<td>0.60** (0.43-0.82)</td>
<td>0.69* (0.49-0.96)</td>
<td></td>
</tr>
<tr>
<td>Either father or mother</td>
<td>N/A</td>
<td>N/A</td>
<td>1.68*** (1.48-1.91)</td>
<td>1.85*** (1.61-2.13)</td>
<td></td>
</tr>
<tr>
<td>Both father and mother</td>
<td>N/A</td>
<td>N/A</td>
<td>Reference</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>Father has a paid job</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>1.21* (1.01-1.46)</td>
<td>1.33** (1.09-1.62)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>N/A</td>
<td>N/A</td>
<td>Reference</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>Mother has a paid job</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>0.98 (0.87-1.10)</td>
<td>1.01 (0.89-1.14)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>N/A</td>
<td>N/A</td>
<td>Reference</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>Household appliances</td>
<td>N/A</td>
<td>N/A</td>
<td>1.00 (0.96-1.03)</td>
<td>0.97 (0.93-1.01)</td>
<td></td>
</tr>
<tr>
<td>e-Learning devices</td>
<td>N/A</td>
<td>N/A</td>
<td>0.76*** (0.71-0.80)</td>
<td>0.76*** (0.73-0.83)</td>
<td></td>
</tr>
<tr>
<td>Home internet access</td>
<td>N/A</td>
<td>N/A</td>
<td>0.80*** (0.76-0.84)</td>
<td>0.79*** (0.75-0.84)</td>
<td></td>
</tr>
<tr>
<td>Parental support</td>
<td>N/A</td>
<td>N/A</td>
<td>0.97 (0.92-1.02)</td>
<td>1.05 (0.99-1.11)</td>
<td></td>
</tr>
<tr>
<td>Parental supervision</td>
<td>N/A</td>
<td>N/A</td>
<td>0.94* (0.89-0.98)</td>
<td>0.97 (0.92-1.02)</td>
<td></td>
</tr>
<tr>
<td>Depression</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1.14*** (1.12-1.16)</td>
<td></td>
</tr>
<tr>
<td>Anxiety</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1.02 (1.00-1.04)</td>
<td></td>
</tr>
</tbody>
</table>

aThe odds ratios and 95% CIs for excessive and pathological gaming addiction behaviors were calculated separately, with leisure gaming as the reference sample.
bIn the crude model, we examined the association between loneliness (continual) and gaming.
cIn Model 1, we additionally adjusted for age and gender.
dIn Model 2, we additionally adjusted for family structure, the father’s job status, the mother’s job status, household appliances (continual), e-learning devices (continual), home internet access (continual), parental support (continual), and parental supervision (continual).
eIn Model 3, we additionally adjusted for depression (continual) and anxiety (continual).
fN/A: not applicable; this variable was adjusted for in subsequent models.
*P<.05.
**P<.01.
***P<.001.

### Familial Factors and Gaming Addiction

Family structure and socioeconomic factors were found to be significantly associated with gaming behaviors. Students from single-parent families (aOR 1.85, 95% CI 1.61-2.13; P<.001) and with unemployed fathers (aOR 1.33, 95% CI 1.09-1.62; P=.006) were at a higher risk of developing pathological gaming behaviors (Table 4). Higher SES reflected by more e-learning devices (aOR 0.78, 95% CI 0.73-0.83; P<.001) and satisfactory internet access (aOR 0.79, 95% CI 0.75-0.84; P<.001) were associated with fewer gaming addiction symptoms. The magnitude of the associations was higher among primary school students compared to secondary school students (Tables S2 and S3 in Multimedia Appendix 1).

Parental support was a significant protective factor for excessive (aOR 0.87, 95% CI 0.82-0.92; P<.001) and pathological (aOR 0.82, 95% CI 0.73-0.93; P=.002) gaming behaviors only among primary school students (Table S2 in Multimedia Appendix 1) but not among secondary school students. Higher perceived parental support, however, was associated with more excessive
and pathological gaming behaviors among secondary school students after adjusting for depression and anxiety (*P*<.001) (Table S3 in Multimedia Appendix 1).

Perceived parental supervision was not significantly associated with gaming disorders among the whole sample, except for pathological gaming behaviors in Model 2 (aOR 0.94, 95% CI 0.89-0.98; *P*=.007) (Table 4). However, in the stratified analysis, the significant protective effect of higher parental supervision for pathological gaming behaviors was found among secondary school students (aOR 0.91, 95% CI 0.86-0.96; *P*=.001), especially for female students (aOR 0.81, 95% CI 0.75-0.89; *P*<.001) (Tables S3 and S5 in Multimedia Appendix 1), but not among primary school students. In terms of gender differences, parental supervision was a significant protective factor for excessive gaming behaviors among male students only (Table S4 in Multimedia Appendix 1). On the contrary, parental supervision was a significant risk factor for excessive gaming behaviors among female students only (Table S5 in Multimedia Appendix 1).

**Discussion**

**Principal Findings**

It is alarming that excessive and potential pathological gaming behaviors were prevalent among adolescent students in Hong Kong when schools were closed owing to the COVID-19 pandemic. Female students in this study were more likely to report loneliness than male students, while those with excessive and pathological gaming behaviors reported more loneliness. The results showed that loneliness was positively associated with gaming addiction when adjusted for sociodemographic characteristics, but the association became negative when depression and anxiety were present. It is noteworthy that familial factors played protective roles in the development of excessive and pathological gaming behaviors only for the younger students.

A recent systematic review on addictive gaming behaviors suggests that the prevalence rates for excessive gaming range from 1.2% to 8.1% and those for pathological gaming range from 1.4% to 2.7% [3]. Empirical studies on gaming behaviors among young people in Hong Kong have been scant. One study conducted in 2014 concluded that 93.2% of 503 high school students had played video or internet games, and 15.7% had a gaming addiction [48]. Our findings indicate that the rates of excessive and pathological gaming behaviors among students are much higher than the local and international rates, and they seem to suggest that there are positive relationships between school closures during the COVID-19 pandemic and addictive gaming behaviors among adolescents. The COVID-19 pandemic definitely disrupted students’ daily routines, limited their outdoor activities, and, hence, easily enabled students to play games for leisure to reduce loneliness and to connect with others [49]. This study has affirmed the positive relationship between loneliness and gaming behaviors that was concluded by previous studies [16,17] and highlighted the situation during a pandemic when many schools are closed down accordingly. However, the conclusion that excessive gaming behaviors increased among students in Hong Kong was not substantiated as we did not have data collected from before the outbreak of COVID-19 for comparison. Nevertheless, when comparing with the findings from previous studies based on school students in Hong Kong, the prevalence of excessive gaming behaviors among the sample of this study is prominent.

It is interesting to find that although male students in this study exhibited significantly higher game addiction behaviors than their female counterparts [7,50], female secondary students were more likely to have a higher risk of pathological gaming behaviors. It is speculated that older female students are more likely to have a desire for closeness with others and dependency on peer relationships, worrying more about abandonment, loneliness, and loss of relationships [51,52] during the school closure period. They were, therefore, more likely to use online gaming as a coping strategy for maintaining social connection in dealing with adverse emotional experiences [53-57] during the isolation period. Truly, any development of prevention and intervention for addictive gaming behaviors must take the relationship between gaming and gender into account [56].

Regarding the mental health of students with gaming behaviors, students with excessive and pathological gaming behaviors were more likely to be depressed, anxious, and lonely [17,58]. However, when these variables were analyzed within multilevel models, loneliness became negatively associated with gaming addiction behaviors. We suspect that feeling depressed may decrease the motivation for socializing and decrease the motivation for gaming among both male and female students [59,60].

Familial factors play a crucial role in the association between loneliness and gaming addiction behaviors, especially for primary school students. It was found that students from single-parent families, with unemployed fathers, or with lower SES were more likely to exhibit gaming addiction behaviors. Considering how SES relates to gaming behaviors, we suspect that those with lower SES had fewer options for leisure activities (eg, music, cooking, and traveling). For primary school students but not secondary students, if their mothers had no paid job and stayed at home, they may have had more parental support and supervision that led to a lesser chance for developing gaming addiction behaviors. Younger children who are supervised and supported by their mothers have been found to be less vulnerable to loneliness and problem gaming behaviors [29,30]. In other words, age also plays an important role in the development of gaming addiction behaviors.

**Strengths and Limitations**

To our knowledge, this is the first study that examines the association between loneliness and gaming addiction behaviors among young people in Hong Kong during the pandemic. Stratified analysis of age and gender subgroups provided in-depth and specific information that may aid in prevention and treatment of gaming addiction. In addition, incorporating familial and mental health factors as extensive and significant confounders in adjusted multivariable analysis may make the associations of gaming addiction and loneliness valid and robust. Also, the classroom surveys with rigorous, systematic, and consistent instructions by trained research assistants could yield more reliable data than online surveys.
Some limitations associated with this study should be noted when interpreting the findings reported above. First, the cross-sectional data generated from this study may make causal inferences difficult. Loneliness may be the cause or consequence of gaming addiction behaviors. The negative association between loneliness and gaming addiction behaviors adjusted for depression and anxiety may also be explained reversely. For instance, depressed students who play games may have reduced their feelings of loneliness. Besides, cross-sectional data make it uncertain whether gaming addiction behaviors increased during the COVID-19 pandemic. A longitudinal or panel study collecting information on gaming involvement and levels of loneliness of school students over time will assist in ascertaining the impact of various factors. Also, collecting qualitative data from target groups and their parents and teachers who are directly in touch with them can enrich the interpretations of the results. In addition, future studies may also include pre-COVID-19 gaming experience, types and frequencies of nongaming leisure activities, and levels of accessibility to outdoor facilities in the survey because they are important confounding factors that may provide contextual information of one’s gaming behaviors. Second, the self-reported responses were less able to capture multifaceted information about loneliness. However, the single-item measure of loneliness, which is well adapted to measure loneliness, has been shown to be valid in previous studies [34]. Third, the generalizability of this study’s findings is limited to upper primary school and lower secondary school students as well as context (ie, based on one city, Hong Kong). A diversified sample that includes in-school and out-of-school adolescents across cities may address this inadequacy.

Implications and Conclusions

Despite these limitations, these findings expand our knowledge regarding gaming behaviors and loneliness among primary and secondary school students in Hong Kong during the pandemic. Findings of this study have potential public health and clinical implications. The results suggest that problematic gaming behaviors are common among young people during the pandemic, and their association with loneliness varies across age groups and genders. Policy makers and designers of prevention programs must consider age and gender as significant factors that will impact the outcomes of such programs. Parents and teachers with young children can organize more nondigital leisure activities to reduce the potential overuse of digital gadgets used for gaming. Findings from this study may also help parents and teachers to plan family and school activities for children and adolescents. If choices for alternative leisure activities are limited due to public health concerns during the pandemic, parental supervision is very important. Parents need to establish ground rules that limit the time for accessing digital gadgets, help younger ones to set priorities for daily routines, and supervise children so they will not play games during their online classes. If parents are also interested in gaming, they can play together with their children to strengthen parent-child interactions, family relationships, and understanding of their children’s interests and habits.

Since gaming can enhance one’s sense of autonomy, competence, and connectedness with others [12], it should not just be considered as a harmful and addictive behavior. If conducted for the right amount of time and in the appropriate contexts, gaming can be a healthy behavior. It is exciting to learn that some functional games have been developed specifically to promote mental well-being during the pandemic [61]. For instance, a game named Shadow’s Edge was developed based on empirical and theory-based foundations, such as narrative therapy and artistic expression, to help players cope with isolation and fear during school closures [62]. Interestingly, it is great to learn that major game publishers around the world and the World Health Organization are supporting the #PlayApartTogether campaign to encourage staying home and maintaining social distance by gaming at home during the lockdown in many countries [63]. In conclusion, gaming can be helpful to the well-being of young people, but can also be harmful, especially to those with lower self-control tendencies. Mature caregivers can help promote positive gaming by providing parental supervision. In addition, more game developers can take steps to design more functional games with social scientists and young people that promote mental well-being and protect players’ health by including planned designs to minimize addictive gaming behaviors.

Acknowledgments

This work was supported by a grant funded by the Hong Kong Research Grant Council (Reference No. 25605418) that was awarded to SZ. We would like to thank the participants of the study and the schools for their assistance with participant recruitment.

Authors’ Contributions

SZ and PW were responsible for the conception of the research question and drafting of the manuscript. SZ was responsible for the study design, data collection, and data cleaning. YZ and PL were responsible for data analysis. JL proofread the manuscript. All authors have approved the final version of the manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1
Supplementary files.
[DOCX File , 78 KB - games_v9i2e26808_app1.docx ]
References


63. KLab Inc. KLab unites with the game industry and WHO #PlayApartTogether campaign to prevent the spread of COVID-19 in Hong Kong: Quantitative Cross-sectional Survey Study JMIR Serious Games 2021;9(2):e26808 [FREE Full text] [doi: 10.2196/26808] [PMID:33969954]
Corrigenda and Addenda

Correction: Virtual Reality App for Treating Eating Behavior in Eating Disorders: Development and Usability Study

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Related Article:
Correction of: https://games.jmir.org/2021/2/e24998
doi:10.2196/29686

In “Virtual Reality App for Treating Eating Behavior in Eating Disorders: Development and Usability Study” (JMIR Serious Games 2021;9(2):e24998) the authors noted two errors.

Due to a system error, the name of one author, Dorothy Odegi, was replaced with the name of another author on the paper, Jenny Nolstam. In the originally published paper, the order of authors was listed as follows:
Billy Sundström Langlet; Jenny Nolstam; Modjtaba Zandian; Jenny Nolstam; Per Södersten; Cecilia Bergh

This has been corrected to:
Billy Sundström Langlet; Dorothy Odegi; Modjtaba Zandian; Jenny Nolstam; Per Södersten; Cecilia Bergh

In the originally published paper, the ORCID of author Jenny Nolstam was incorrectly published as follows:
0000-0001-6120-9412
This has been corrected to:
0000-0002-9928-2778

The correction will appear in the online version of the paper on the JMIR Publications website on April 20, 2021, together with the publication of this correction notice. Because this was made after submission to PubMed, PubMed Central, and other full-text repositories, the corrected article has also been resubmitted to those repositories.

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doi:10.2196/29686
PMID:33878026
Correction: Design and Evaluation of User-Centered Exergames for Patients With Multiple Sclerosis: Multilevel Usability and Feasibility Studies

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Related Article:
Correction of: https://games.jmir.org/2021/2/e22826
doi:10.2196/30326

In “Design and Evaluation of User-Centered Exergames for Patients With Multiple Sclerosis: Multilevel Usability and Feasibility Studies” (JMIR Serious Games 2021;9(2):e22826) the authors noted two errors.

In the originally published manuscript, the images displayed as Figures 9-13 were associated with the incorrect figure numbers. Figure captions and numbering were otherwise unaffected. The following changes have been made in the corrected version of the manuscript:

- The image displayed as Figure 9 has been corrected to appear as Figure 10.
- The image displayed as Figure 10 has been corrected to appear as Figure 11.
- The image displayed as Figure 11 has been corrected to appear as Figure 9.
- The image displayed as Figure 12 has been corrected to appear as Figure 13.
- The image displayed as Figure 13 has been corrected to appear as Figure 12.

In addition, under the section “Qualitative Data,” the following sentence appeared in the originally published version:

“In summary, all participants reported an enjoyable, motivating, varied, and fun experience with the exergames, which was a completely new thing for most of them (Figures 9, 11, and 12).”

This has been corrected as follows to properly format in-text references to figures according to journal style:

“In summary, all participants reported an enjoyable, motivating, varied, and fun experience with the exergames, which was a completely new thing for most of them (Figure 9, Figure 11, and Figure 12).”

The correction will appear in the online version of the paper on the JMIR Publications website on May 12, 2021, together with the publication of this correction notice. Because this was made after submission to PubMed, PubMed Central, and other full-text repositories, the corrected article has also been resubmitted to those repositories.