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Original Paper

Improving Maximal Strength in the Initial Postoperative Phase After Anterior Cruciate Ligament Reconstruction Surgery: Randomized Controlled Trial of an App-Based Serious Gaming Approach

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Abstract

Background: Anterior cruciate ligament reconstruction surgery is one of the most common orthopedic procedures. One of the main factors that influence the outcome is regaining strength in the postoperative phase. Because anterior cruciate ligament reconstruction surgeries are often performed in young patients, we combined the concept of prehabilitation with an app-based serious gaming approach to improve maximal strength postoperatively.

Objective: Our objective was to conduct a prospective randomized trial to evaluate whether an app-based active muscle training program (GenuSport Knee Trainer) can improve postoperative strength by starting rehabilitation immediately after primary anterior cruciate ligament reconstruction surgery.

Methods: We designed a pilot study in which we randomly assigned patients receiving primary anterior cruciate ligament reconstruction to either the serious gaming training (intervention) group or a conventional rehabilitation (control) group. Except for the serious gaming-based training, both groups followed the same postoperative treatment protocol. Outcome parameters were absolute and relative change in maximal strength, as well as the International Knee Documentation Committee Subjective Knee evaluation form, Knee Injury and Osteoarthritis Outcome Score, and Lysholm Knee Score.

Results: In total 26 patients agreed to participate (14 patients in the intervention group and 12 patients in the control group, 1 of whom was lost to follow-up). We noted a difference in absolute maximum strength between the exergaming intervention and the control groups. Mean maximum strength preoperatively was 155.1 (SD 79.2) N in the intervention group (n=14) and 157.0 (SD 40.8) N in the control group (n=11). Postoperative mean maximum strength was 212.8 (SD 78.5) N in the intervention group and 154.5 (SD 27.1) N in the control group. Mean absolute change in maximum strength was 57.7 (SD 95.2) N in the intervention group and –4.8 (22.2) N in the control group. The analysis of covariance model with absolute change as the dependent variable and treatment group and baseline maximum strength as covariates showed a relevant difference in relative change between treatment groups (intervention – control) of 59.7 N (95% CI 10.1-109.3; *P*=.02). Similarly to the absolute increase, the relative change in maximum strength was relevantly higher in the exergaming group. The mean relative change in maximum strength was 1.7 (SD 1.17) in the intervention group and 1 (SD 0.13) in the control group. No adverse events or problems were reported during the study period.

Conclusions: Implementation of an app-based active muscle training program in the early postoperative therapy scheme was associated with an improvement in maximal strength. Therefore, we considered the use of GenuSport training after anterior cruciate ligament reconstruction to be a helpful complement to rehabilitation after anterior cruciate ligament reconstruction surgery to improve strength in the early postoperative phase. To our knowledge this was the first study to analyze immediate postoperative serious gaming-based training with the GenuSport device based on strength improvement.

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KEYWORDS

serious gaming; knee trainer; games, experimental; exercise therapy; physical and rehabilitation medicine; anterior cruciate ligament reconstruction; knee injuries

Introduction

Background

The rupture of the anterior cruciate ligament (ACL) is one of the most common ligament sports injuries of the knee joint. The number of cruciate ligament operations performed is quite high and has increased continuously over the last years. Because ACL ruptures often occur during sport activities, a relevant number patients are under the age of 40 years [1].

Over the past years, many changes have been achieved, especially in surgical reconstruction techniques. Nonetheless, especially in the last decade, studies have also focused on rehabilitation after ACL reconstruction and on possible strategies to improve outcomes. It is well known that, in addition to several other preoperative and postoperative factors, insufficient rehabilitation leads to a poor outcome in terms of restricted range of motion, strength, and overall knee function, resulting in arthrofibrosis [2-4]. Due to these improvements, the risk of arthrofibrosis has been reduced to around 5% [5].

The tremendous importance of early rehabilitation in all fields of medicine, for example, after neurological disorders (eg, stroke) or surgeries in general, has been understood over the last decades. That is why new concepts have been implemented in the perioperative and postoperative phases. The first concept of enhanced recovery after surgery, consisting mostly of protocols in which patients were guided by physiotherapists, already led to a clinically significant improvement in rehabilitation [6-8]. New concepts have been developed focusing on training, in which patients train at home under the guidance of a physiotherapist (telerehabilitation). This concept is already well accepted in the case of total knee arthroplasty and has shown results comparable with normal outpatient rehabilitation protocols [9,10]. Along with the concept of telerehabilitation, new training devices are being used in rehabilitation, making direct biofeedback-guided training therapy at home possible [11-13]. This biofeedback-guided training has now been combined with the concept of exergaming, in which patients train with devices in conjunction with app-based systems that allow patients to train specific aspects such as range of motion or strength by successfully completing games optimized for the each training process [14,15].

One problem of most available feedback-controlled training systems is that the exercises mainly focus on range of motion, and training is only possible with an acceptable range of motion. Therefore, we previously tested a device in rehabilitation after total knee arthroplasty focusing on feedback-controlled active muscle training uncoupled from range of motion. The GenuSport Knee Trainer improved the outcome after total knee arthroplasty especially in the immediate postoperative phase [16]. Additionally, high compliance rates were noted [16-19].

Objective

We postulated that training with our device in the initial postoperative phase after ACL reconstruction surgery would improve the overall postoperative outcome, thereby helping the predominantly young patients on their return to normal life and especially to an early return to sports. In comparison with other studies that mainly focused on improved range of motion rather than strength improvement, our device can be used directly after surgery [20]. This allows for a fast-track rehabilitation concept that combines the idea of prehabilitation with serious exergaming strategies.

To our knowledge, no studies have analyzed the effect of muscle strength–based training immediately after ACL surgery. We developed this randomized controlled trial to address this lack.

Methods

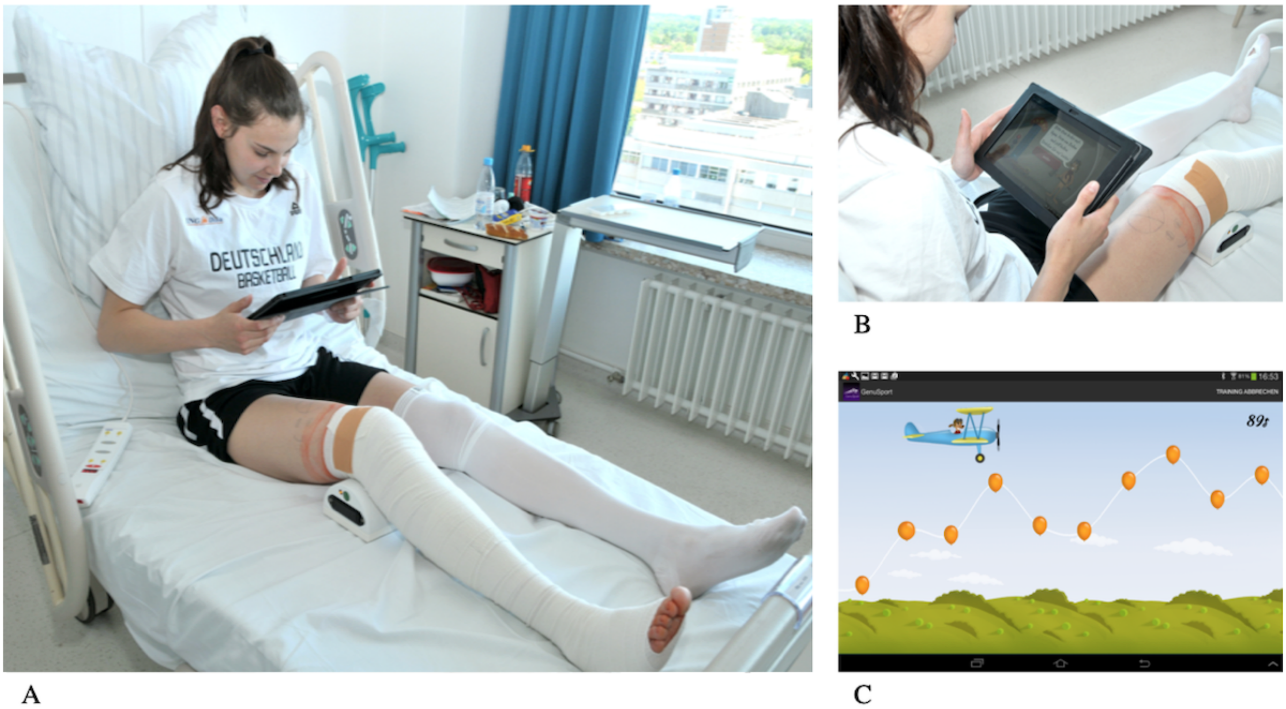
Study Design

In this prospective randomized controlled trial, we recruited patients awaiting primary ACL reconstruction surgery at a single tertiary health care center between April 2016 and February 2018. The trial is registered; Multimedia Appendix 1 [21]).We obtained ethical approval from the Hanover Medical School ethics committee. Due to different surgical approaches and postoperative treatment protocols, we included patients between 13 and 46 years of age. The main exclusion criteria were additional knee injuries that altered the postoperative treatment protocol (such as meniscal suturing, collateral ligament repair, or regenerative cartilage treatment) and unwillingness to participate in the study. We used computer-based randomization by generating a list of randomized numbers that were provided in sealed envelopes by an independent examiner. The postoperative treatment protocol was identically standardized, apart from the use of the GenuSport Knee Trainer by the intervention group. Pain management was the same for all patients, and none of the patients received a continuous peripheral nerve block. The postoperative physiotherapy protocol included gait training, assisted walking with crutches, active and passive knee mobilization, strength exercises, and stair climbing. In the training intervention group, each patient was additionally provided with a GenuSport Knee Trainer device (prototype plus tablet with software app) with the active knee extension training program for 3 weeks. Otherwise, the postoperative protocol was identical in both the intervention and control groups. Patients were required to train up to 5 times daily with the knee trainer starting on the day of surgery.

GenuSport Knee Trainer

We previously described the Knee Trainer device [16-19]. It consists of a strength-monitoring unit with 3 integrated sensors that is placed in the popliteal area and a tablet with the app, which transfers the raised force into the game modus (Figure 1). Each training session in our study takes around 5 minutes and is performed autonomously by patients in their bed with 45° upper-body elevation while the patient holds the tablet in both hands. By simply pushing the knee downward onto the measuring unit, the patient can apply force. It is of tremendous importance that during the entire training session, the leg is not rotated, the hip is not lifted, and the heel is in contact with the mattress. The training app has 2 modes: 1 for the training itself and 1 for analysis. The training mode includes 2 different games: 1 for maximal strength, in which the patient has to apply maximal force for 5 seconds, and 1 longer game lasting 100 seconds, in which the patient controls the flight course of an airplane by applying different forces. The aim is to destroy the balloons with the propeller and to avoid the dark clouds. Direct feedback is provided after each game on a summary screen presenting the results [17].

Figure 1. The GenuSport knee trainer. (A) The device is correctly placed under the patient's knee. (B) The patient holds the tablet while in an upright position. (C) The mobile app shows the game (lasting 100 s) in which the patient controls the flight course of an airplane by applying various forces. The aim is to destroy the balloons with the propeller and to avoid the dark clouds.



Blinding

Due to the nature of this study, blinding of patients was not possible.

Intervention

Surgeries were performed by the same senior physician. In all patients, hamstring grafts were used. The fixation technique included femoral and tibial screw fixation (Storz Medical AG, Tägerwilen, Switzerland), as well as extracortical fixation (Storz Medical).

Outcomes

We analyzed all patients before and 6 weeks after surgery. We measured function using the International Knee Documentation Committee Subjective Knee (IKDC) evaluation form, Lysholm Knee Score, Tegner activity scale, Knee Injury and Osteoarthritis Outcome Score (KOOS), the maximum strength, and a visual analog scale. Additionally, we measured the femoral diameter 10 cm and 20 cm above the joint line.

We analyzed change in maximum strength as both the absolute difference between the week-6 and presurgery values (6 weeks – presurgery) and as the relative change (6 weeks / presurgery). We compared the change in maximum strength on both scales between the intervention and control groups using an analysis of covariance (ANCOVA) model with change in maximum strength as the dependent variable and presurgical maximum strength and treatment group as the independent variables.

Statistical Evaluation

We performed statistical analysis using IBM SPSS Statistics version 25 (IBM Corporation).

Results

Participants

In total 26 patients agreed to participate (14 patients in the exergaming group and 12 patients in the control group). One patient of the control group was lost to follow-up; hence, we analyzed 25 patients in total (14 intervention patients vs 11 control group patients) (Figure 2).

Baseline Characteristics

Table 1 lists the baseline characteristics of the included patients regarding age, sex, body mass index and preoperative scores and strength. The 2 groups did not differ in terms of these criteria.

Compliance in the Knee Trainer Group

We saw high compliance rates within the intervention group. None of the patients needed more than 1 instruction to use the knee trainer. Of the 14 patients in this group, 11 (79%) trained with the device regularly (around 17 times a week), whereas 3 patients (20%) did not comply with the training frequency of at least 7 times a week.

Clinical Outcomes

Analysis of the data showed a relevant difference in the absolute increase of maximum strength between the exergaming group (n=14) and the control group (n=11). Postoperative mean maximum strength was 212.8 (SD 78.5) N in the intervention group (n=14) and 154.5 (SD 27.1) N in the control group (n=11). Mean absolute change in maximum strength was 57.7 (SD 95.2) N in the intervention group and –4.8 (SD 22.2) N in the control group. The ANCOVA model with absolute change as the dependent variable and treatment group and baseline maximum strength as covariates showed a relevant difference in absolute change between treatment groups (experimental – control) of 59.7 N (95% CI 10.1-109.3; *P*=.02) (Figure 3).

Figure 2. Consolidated Standards of Reporting Trials (CONSORT) study flow diagram. ITT: intention to treat; MCL: medial collateral ligament.

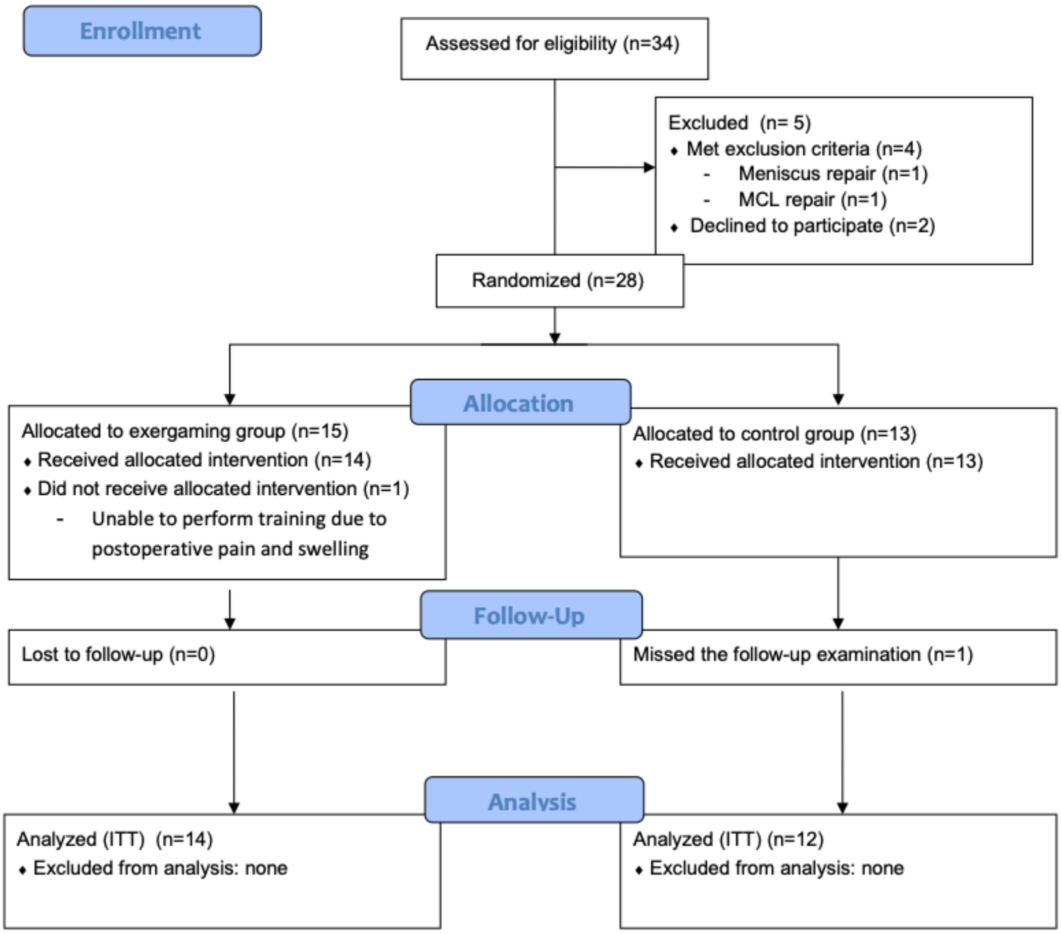
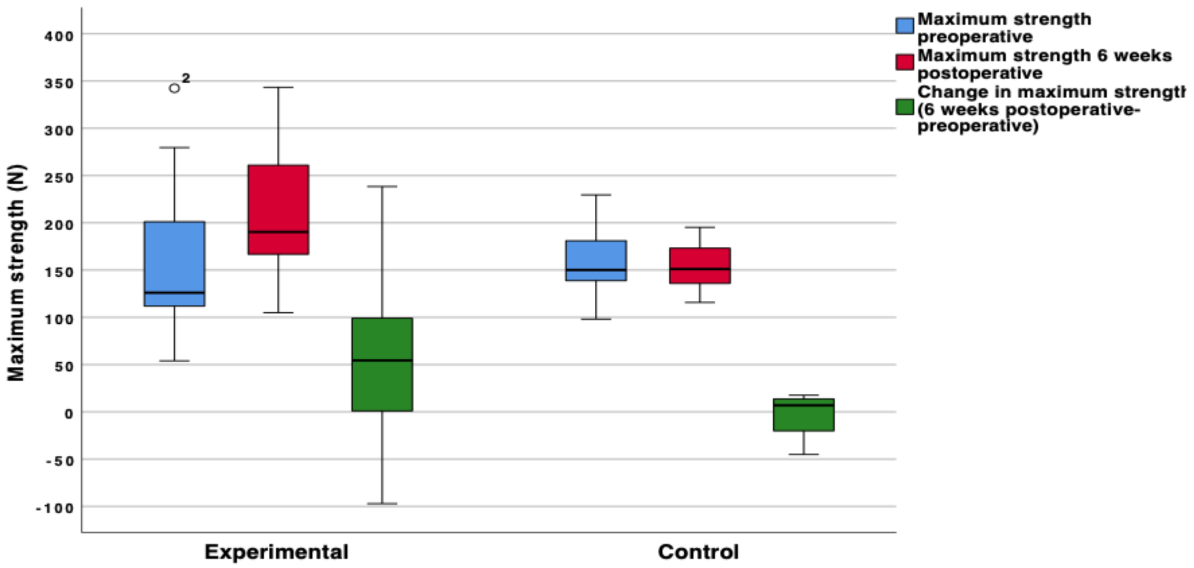


Table 1. Baseline characteristics and outcomes of the study groups.

Characteristics	Intervention group (n=14)	Control group (n=12)	Total (n=26)
Sex (women), n (%)	8 (57)	6 (50)	14 (54)
Body mass index (kg/m^2), mean (SD)	24.6 (5.74)	25.45 (4.02)	25.45 (4.02)
Age (years), mean (SD)	24.86 (9.71)	25.58 (6.4)	25.19 (8.2)
Tegner activity scale score, mean (SD)	7 (2.25)	6.33 (1.61)	6.69 (1.98)
Time between operation and final examination (days), mean (SD)	46.50 (8.58)	44.92 (5.53)	45.77 (7.24)
GenuSport Knee Trainer maximum strength (kg), mean (SD)			
Operated leg	15.81 (8.06)	16 (4.16)	15.90 (6.44)
Nonoperated leg	17.73 (6.59)	17.62 (3.91)	17.68 (5.42)
IKDC[a] 2000 subjective, mean (SD)	50.16 (16.10)	61.11 (14.34)	55.22 (16.00)
Symptoms/stiffness	53.32 (22.91)	65.77 (18.56)	59.19 (20.08)
Pain	63.52 (24.03)	70.37 (19.55)	66.68 (21.92)
Function/daily living	71.64 (23.63)	83.16 (14.78)	76.71 (20.68)
Function/sports	31.16 (26.18)	48.13 (25.74)	38.99 (26.87)
Quality of life	22.32 (16.02)	31.94 (17.16)	26.76 (16.94)
Lysholm activity scale score, mean (SD)	55.79 (21.51)	63.17 (18.37)	59.19 (20.08)
Single assessment numeric evaluation, mean (SD)	49.93 (28.06)	61.25 (18.23)	55.15 (24.26)
Visual analog scale score, mean (SD)	2.61 (2.34)	2.53 (1.74)	2.57 (2.04)

[a]IKDC: International Knee Documentation Committee Subjective Knee evaluation form, 2000 revision.

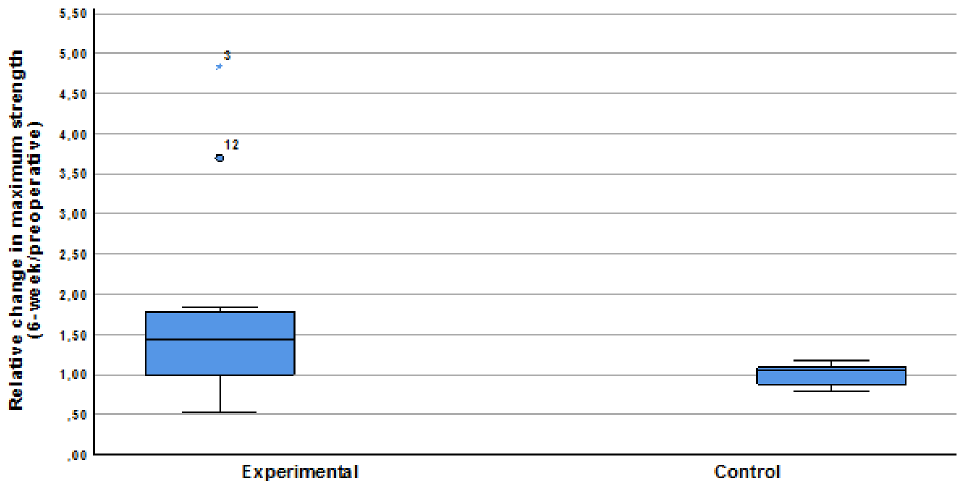
Figure 3. Box and whisker plot of the experimental and control groups comparing absolute change in maximum strength 6 weeks after surgery versus before surgery (6 weeks – preoperative), depicting the 25th to 75th percentile in the box with the mean indicated by the bar in the box. The whiskers indicate the 10th and 90th percentiles. One outlier in the experimental group is depicted by the circle.



Relative change in maximum strength was higher in the exergaming group. Mean relative change in maximum strength was 1.7 (SD 1.17) in the intervention group and 1 (SD 0.13) in the control group. The ANCOVA model with relative change as the dependent variable and treatment group and baseline maximum strength as covariates showed a relevant difference in relative change between treatment groups (experimental – control) of 0.67 (95% CI 0.054-1.299; *P*=.03) (Figure 4).

A subgroup analysis of patients who trained more than 2 times a day showed no difference in absolute and relative changes in maximum strength, but we saw a clear trend to higher strength levels in the group of patients that trained more than 2 times a day.

Figure 4. Box and whisker plot of the experimental and control groups comparing relative change in maximum strength 6 weeks after surgery versus before surgery (6 weeks / preoperative), depicting the 25th to 75th percentile in the box with the mean indicated by the bar in the box. The whiskers indicate the 10th and 90th percentiles. Two outliers in the experimental group are depicted by the circle and the star.



Changes in clinical scores (eg, IKDC, KOOS, Tegner activity scale, Lysholm Knee Score, and visual analog scale) were not different between the 2 study groups (Table 1).

Adverse Events

Neither group reported adverse events during the study period. In particular, there were no readmissions to the hospital, reoperation for any reason, infections, or falls.

Discussion

Principal Findings

Following the progress made in information and communication technology, new technology-based rehabilitation strategies have been incorporated into various medical fields. In this context, new protocols for rehabilitation have been developed. These serious games for functional rehabilitation are considered to improve the whole rehabilitation process. Notably, in most published studies, patient compliance has been very high. This indicates a high motivation for training with exergaming devices. These results for serious games have been reported in all fields of medicine (eg, psychiatry, internal medicine, neurology, and musculoskeletal medicine) [22-25]. Although our patient population was quite small, the high compliance rate we observed is comparable with previous studies.

All of the patients allocated to the exergaming group completed the entire follow-up protocol. In the exergaming intervention group, about 80% showed good compliance, meaning they trained at least once a day, and none of these patients needed face-to-face contact during the 3-week training period. This indicates that the device design is user-friendly and that people from different age groups can use the device autonomously after adequate initial instruction. Ideally, instruction would start before surgery. We think that there is also potential for using the device in the preoperative phase to improve preoperative strength, which is known to positively influence the postoperative outcome [3,26,27].

We saw a slight trend in the frequency of daily training decreasing over the 3 weeks. We think that this might have been because the gameplay of the 2 game modes that were provided did not develop over time in difficulty or the main game principle. To achieve the goal of implementing serious gaming into the rehabilitation of musculoskeletal disorders, existing systems must be evaluated and further developed [22]. To this end, we are developing a 3-level system with the difficulty increasing at every level. We also think that the patient’s fitness needs to be evaluated preoperatively and that the game difficulty would be adapted to the patient’s fitness level. We are also trying to implement different surroundings, such as desert, space, and ocean.

The most important problem in feedback training strategies is that nearly all of them require an adequate range of motion. Therefore, therapy cannot start immediately after surgery because the patient is not able to properly move his or her legs. We designed our study to assess whether it is possible to positively influence the immediate postoperative phase by following a novel exergaming-based training protocol based on strength training rather than on range of motion as in other protocols. Other recently published studies of feedback-controlled training after total knee arthroplasty started their programs not before day 7 [13]. Results of feedback-controlled range-of-motion training were very promising and showed significant improvements in the range-of-motion outcome [20]. In comparison with range-of-motion protocols, the most important takeaway from our study is the relevant improvement in the maximum strength relative to that obtained with the conventional rehabilitation protocol. Regaining strength is an important parameter in the functional outcome [28]. To our knowledge, the protocol we analyzed is unique in that it is possible to train immediately after surgery. We therefore think that our protocol can help to improve the overall outcome in addition to range-of-motion–based strategies. These aspects need to be tested in further studies, and the device should also be combined with training devices focusing on range of motion.

Because serious gaming has already been incorporated into other fields of medicine with good results, musculoskeletal surgeons should also implement these promising strategies both before surgery and into rehabilitation after common procedures, as well as in conservative orthopedics. The good results in different age groups suggest that serious gaming is applicable in nearly all periods of life [29-31].

Limitations

The main limitations of our study were a comparatively small patient population and a short follow-up period of 6 weeks. This is due to the fact that our approach to the immediate postoperative strength-based training has not been implemented in postoperative protocols. Hence, we conducted this pilot study to evaluate the effect of exergaming-based training on the early postoperative phase as a basis for further studies.

Conclusion

To our knowledge, this was the first study that successfully implemented a serious gaming-based strength training device into early rehabilitation after ACL surgery. The results are promising; hence, we think that this technology has high potential in this area of rehabilitation, as well as in prehabilitation of musculoskeletal disorders. Further studies are needed to test these concepts and results. If the results of these further studies are as promising as the results of our study, we think that this might be a big step toward implementing such training strategies into routine clinical protocols, especially since the positive aspects of serious gaming are seen in all age cohorts.

Conflicts of Interest

TSWS is the head of GenuSport GmbH.

Editorial notice: This randomized study was not prospectively registered. The editor granted an exception of ICMJE rules for prospective registration of randomized trials because the risk of bias appears low and the study was considered formative. However, readers are advised to carefully assess the validity of any potential explicit or implicit claims related to primary outcomes or effectiveness, as retrospective registration does not prevent authors from changing their outcome measures retrospectively.

Multimedia Appendix 1
CONSORT-EHEALTH checklist V1.6.1.
[PDF File (Adobe PDF File), 529 KB - games_v8i1e14282_app1.pdf]

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Abbreviations

ACL: anterior cruciate ligament
ANCOVA: analysis of covariance
IKDC: International Knee Documentation Committee Subjective Knee
KOOS: Knee Injury and Osteoarthritis Outcome Score

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Original Paper

Engaging African American Youth in the Development of a Serious Mobile Game for Sexual Health Education: Mixed Methods Study

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Abstract

Background: Although teen pregnancy rates decreased dramatically in the United States over the past decade, the rates of sexually transmitted infections (STIs) among adolescents and young adults increased. STI rates disproportionately affect African American youth and young adults. Innovative, accessible, and culturally relevant sexual health interventions are urgently needed.

Objective: This study aimed to identify the optimal modality for a game-based sexual health intervention; develop the educational, entertainment, and technological aspects of the serious game; and demonstrate its usability and acceptance by the target population.

Methods: This project was grounded in formative data collection with community-based participatory research principles and practices combined with a user-centered design and development approach. Sexually Active Adolescent–Focused Education (SAAFE) was developed using input and feedback from African American youths aged 15 to 21 years who participated in a youth advisory board and focus group discussions to inform the co-design and cocreation of the serious game. The process was highly iterative with multiple sessions for user input following design changes. It proceeded in 3 stages. Social cognitive theory and problem-solving theory were leveraged to provide evidence-based, trauma-informed education through a serious game. Usability testing assessed the quality of user experience with the prototype.

Results: Across all 3 stages, a total of 86 self-identified African American males and females aged 15 to 21 years from the District of Columbia and Birmingham, Alabama, participated. Participants requested a dating simulation game. They wanted SAAFE to be customizable, realistic, entertaining, educational, modern, and experiential, linking consequences to their gameplay decisions. Usability testing resulted in an initial System Usability Survey score of 77.7, placing the game in the 82nd percentile and above average for usability.

Conclusions: Initial results suggest that the SAAFE prototype is a promising intervention to engage African American youth in sexual health education using a role-playing game. If proven efficacious, the game has the potential to meet the need for sex education, counterbalance unhealthy portrayals of sex in popular media, and respond to the disparities in the STI epidemic.

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KEYWORDS

sexual health; sex education; African Americans; youth; adolescents; video games; games, experimental; community-based participatory research; user-centered design

Introduction

Background

The sexual health of adolescents and young adults in the United States remains a public health crisis. Youths aged 15 to 24 years acquire half of all new sexually transmitted infections (STIs), yet many do not obtain screening [1]. A 2013 survey revealed that only 27% and 9.8% of 15- to 25-year-old sexually experienced females and males, respectively, had been tested for STIs in the past 12 months [2]. Significant disparities in sexual health also exist among the youth. African Americans make up 13% of the US population, but in 2017, they accounted for 27.7% of new chlamydia infections, 31.8% of new syphilis infections, 39.7% of new gonorrhea infections, and 43% of new HIV infections [1,3]. African American high school students are significantly more likely than other race and ethnic groups to identify 4 or more sexual partners within their lifetime [4].

Improving the sexual health of adolescents and young adults and reducing racial disparities are public health priorities included in Healthy People 2020. However, analysis of the Center for Disease Control and Prevention’s National Survey of Family Growth found that receipt of formal sex education is both inadequate and on the decline in the United States. Between 2011 and 2013, although approximately three-quarters of teens received education on STIs and HIV, less than three-quarters were taught how to say no to sex and only half received education on condoms [5]. New approaches to the delivery of sexual health content that is engaging to the youth and culturally specific are needed.

Serious video games are increasingly used for health education purposes and show promise as educational tools [6]. A serious video game is defined as “an interactive computer application, with or without a significant hardware component, that has a challenging goal, is fun to play with, incorporates some concept of scoring, and imparts in the user a skill, knowledge or attitude which can be applied in the real world” [7]. The main difference between a serious video game and a video game in general is that the former is developed for pedagogical purposes beyond the entertainment and recreational goals of the latter [8].

Young Americans, regardless of race or ethnicity, are prolific video game players [9]. About 90% of teens and 67% of young adults report playing video games, and about a quarter of teens believe that they spend *too much time* on these games [10-12]. African Americans are more likely to view video games positively (ie, promote teamwork and communication and problem-solving and strategic thinking skills), which may reflect greater engagement among this group [13]. Video games can be played on a mobile device (such as a phone or a tablet), a gaming console, or a computer, but African American youth are more likely to depend on their mobile devices to access video games on the Web [14].

Sexual health is an emerging focus for serious video games, and the results are promising [15]. A good example is *PlayForward: Elm City Stories* developed by the Play2Prevent Lab at the Yale Center for Health & Learning Games. It showed promise in improving sexual health knowledge and skills among youths of color aged 11 to 14 [16]. Another example is *It’s Your Game* developed by the University of Texas Prevention Research Center. *It’s Your Game* is a computer-based sexual health education game designed for middle schoolers of any race and ethnicity in a classroom setting; it demonstrated effectiveness in delaying initiation of sexual activity [17-19]. However, no comprehensive sexual health game has been developed *with* older African American adolescents and young adults for use on a mobile platform.

Objectives

This study describes the development of a mobile-based serious video game for sexual health education, Sexually Active Adolescent–Focused Education (SAAFE), designed specifically with and for youths who identify as African American. The goal of our intervention is to promote healthy sexual behaviors that, among other things, help reduce the disproportionate burden of STIs among African American youth.

Before launching intervention development, our multidisciplinary scientific team convened a panel with expertise in clinical service delivery of adolescent sexual health, developmental psychology, and mobile health (mHealth) technology. The purpose of the panel was to assist our team with content development, align the project with existing research, and identify behavioral targets of interest.

Social cognitive theory (SCT) and problem-solving theory (PST) provided theoretical frameworks for design and development decisions. SCT describes the multiple, reciprocal influences on health behaviors, including individual experiences, beliefs, and environmental factors [20]. SCT states that “knowledge of health risks and benefits of different health practices, perceived self-efficacy, outcome expectations about the expected costs and benefits, health goals people set for themselves, and perceived facilitators and social and structural impediments” can translate knowledge into effective health practices [20]. Building self-efficacy (confidence in one’s ability to perform a desired health behavior) and self-regulation (goal setting and planning) are key constructs of SCT that guided the development of SAAFE. PST describes a *problem-solving* process whereby an individual “gains new pieces of information and finds out gradually which circumstances affect, or don’t affect the removal of the cause, the conflict or the difficulty” [21].

This paper describes the scope and process of our work, presents findings, describes the research leading to the final serious game, shares lessons learned, and outlines plans to proceed to the next phase: an outcome evaluation; gaming optimization; and, if impact is demonstrated, widespread implementation.

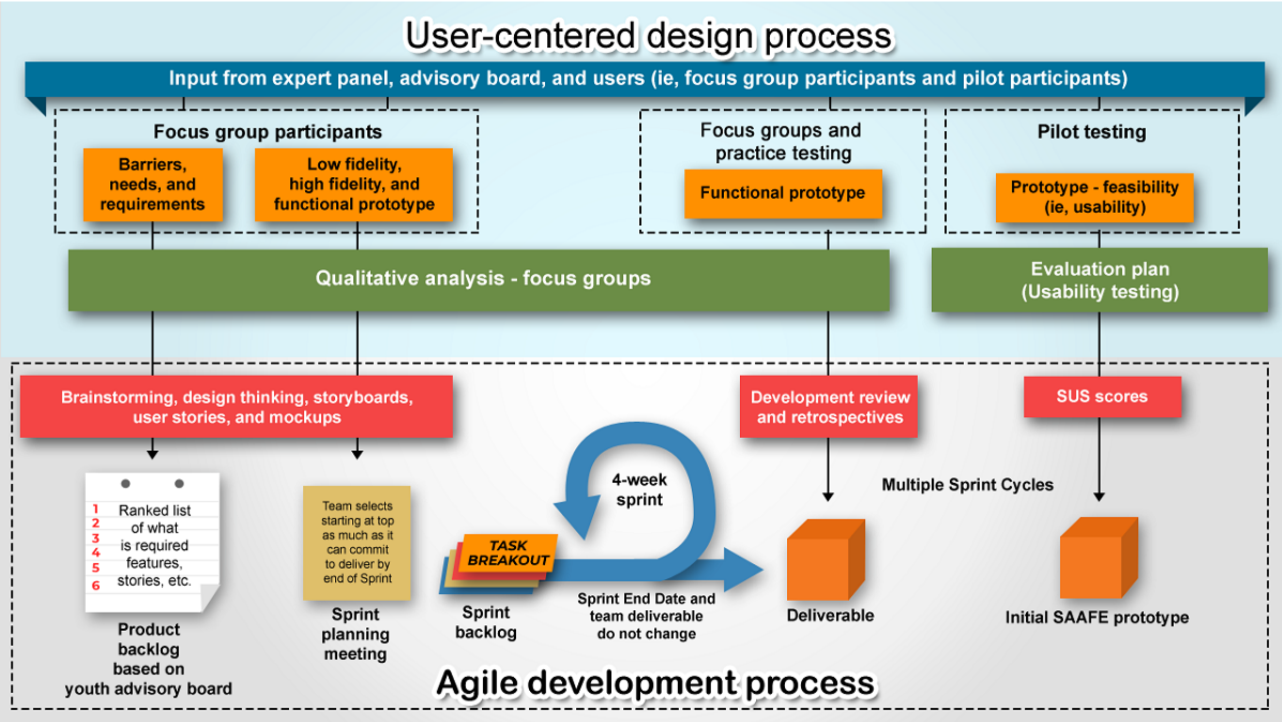
Methods

Overview

A community-based participatory research approach, integrated with user-centered design and development methods, effectively informed the development of SAAFE. The process was highly iterative, with multiple sessions for user input following design changes. It proceeded in 3 stages, described below. Across all stages, a total of 86 self-identified African American males and females aged 15 to 21 years from the District of Columbia (DC) and Birmingham, Alabama (AL), participated.

First, a youth advisory board provided input to develop a game prototype. This prototype was then tested for usability. Subsequently, we conducted a series of focus groups to further develop and finalize the game. We adopted an Agile methodology, which is an iterative process whereby the game is built incrementally in biweekly development cycles, called *sprints*, that allows for user feedback after each cycle. Editing and developing the game between focus groups allowed participants to systematically review our progress. Figure 1 shows an illustration of this framework for SAAFE development.

Figure 1. User-centered design processes. SAAFE: Sexually Active Adolescent–Focused Education; SUS: System Usability Scale.



This study was approved by the Institutional Review Boards of the MedStar Health Research Institute and the University of Alabama at Birmingham.

Participants

African American youths aged 15 to 21 years were included in the study. Females who were pregnant or within 6 weeks post-partum were excluded because attitudes and behaviors during the prenatal and immediate postpartum period may be systematically different. Written informed consent was obtained for participants aged 18 years or older; parental consent with the adolescent's assent was obtained for participants younger than 18 years.

Initially, 6 African American youths were recruited from the DC area to participate in the youth advisory board and inform the initial prototype development. Participants of the youth advisory board responded to a description of the work made available at nonprofit organizations focused on the youth and an adolescent health center. A study team member met with the interested youths to explain the project, review eligibility criteria, and obtain consent and assent to participate.

New participants then tested the SAAFE game prototype and completed a usability survey. Recruitment occurred at an adolescent health center in DC over 4 weeks. Prospective participants were informed about the study by a health center team member. If interested, they were asked to complete a short questionnaire to verify eligibility as described above, and then, the participants signed an informed consent document. They were then provided access to the game.

Usability data were obtained for the prototype to ensure acceptability. Results were promising, so the team held a series of focus groups with new participants to guide additional development. To capture additional geographic variability in youth perspectives, we expanded our sample to include Birmingham, AL. Like DC, AL has a high STI burden. Participants were recruited from adolescent health and community centers to participate in focus groups over the course of 9 months. Many youths took part in 2 or more focus groups. Each focus group lasted about 2 hours and included 6 to 10 youths. Two groups ran concurrently and reviewed the same topics in AL; 1 group included youths who identified as lesbian, gay, bisexual, transgender, queer/questioning, intersex, or asexual (LGBTQIA) and the second group included youths in which LGBTQIA status was not specified. The LGBTQIA status of the DC groups was not specified. Focus group discussions were held in private rooms and were led by a trained focus group moderator. Participants were asked to sign an agreement to keep the identity of others confidential. They received a US $50 cash incentive for participating in each focus group.

Game Development Process

The project began with a review of the scientific literature and consultation with a panel of experts in the fields of adolescent sexual health, child development, and mHealth intervention strategies to define outcome parameters and behavioral health targets. We then recruited the youth advisory board to inform initial design decisions and prototype development. Gaming experts with graduate and undergraduate degrees programmed the game with assistance from graphic artists, script writers, and audio/visual specialists.

Youth Advisory Board

Guided by our design and development framework of maximizing engagement of community users, the initial design and features of the game were driven by 4 meetings with the youth advisory board that took place in DC over the course of 8 months with 2 months between the first 3 meetings and 4 months between third and fourth meetings. An overview of the topics discussed is presented in Textbox 1. The initial SAAFE game prototype—an initial version of the game—was developed and refined based on feedback obtained after each meeting.

Textbox 1. Overview of the topics explored with the youth advisory board.

Meeting 1

- Introduction
- Video game use habits
- Sexual health topics
- Sexual language identification

Meeting 2

- Game concept
- Storyline, character, and scene design

Meeting 3

- Storyboard design
- Game navigation

Meeting 4

- Game play
- Feedback on graphics and game content

The resulting prototype was then shared with the youth advisory board. They were given tablets with the game preinstalled. Members reviewed the game instructions and provided feedback on clarity, language, length, and ease of understanding. They played the prototype for at least an hour and provided feedback on content, artwork and design, minigames, dialogue, and entertainment value. Meeting facilitators recorded the session and developed a list of key recommendations from members. The design team listened to the recording and used the key recommendations list to inform the final refinements before usability testing.

Usability Testing

Youths participating in usability testing were provided a tablet with the game preinstalled and a unique user code. They played the game for an hour and then completed the System Usability Scale (SUS), a highly reliable (Cronbach alpha of .91) 10-item Likert scale that measures the user's experience with an electronic tool [22]. Specifically, SUS measures function, efficiency, effectiveness, and satisfaction. It is the most common questionnaire used in assessing system usability. Possible scores range from 0 (not usable) to 100 (perfectly usable). A score of 68 is considered average, so a score above 68 implies that a tool has greater than average usability. We asked 4 additional questions with a 1 to 5 scale (strongly disagree to strongly agree): "I would consider downloading the SAAFE game to play," "I learn a lot about STIs using the SAAFE game," "I would recommend the SAAFE game to a friend," and "Overall, I am satisfied with playing the SAAFE game." The goal was to achieve an average score of 4 or higher.

Focus Groups

Usability metrics for the SAAFE prototype were promising, so we proceeded to conduct focus groups, which were an integral part of our user-centered, highly iterative process of cocreation. Focus group participants reviewed content and design, and we modified the game based on those findings. We used Microsoft PowerPoint and YouTube videos to aid in discussions of features and scenarios. We discussed dialogue with printouts given to each participant. We provided tablets with the game preinstalled for gameplay. Feedback from each focus group was analyzed, compared and contrasted, and incorporated into the game before the next focus group. Table 1 provides an overview of the topics explored in each focus group.

Table 1. Overview of focus group discussion topics.

Focus group number	Topic	Sample questions
Focus groups 1 and 2	General feedback and features	• What are your general impressions? • How do you feel about the game's destinations and setting, characters and interactions, multiplayer capability, minigames, and education? • What are the most important changes we should make? • What ideas do you have for other features?
Focus groups 3 and 4	Scenarios	• Review of storylines and possible outcomes • Are the scenarios realistic? • What else would you like to see happen?
Focus groups 5-7	Dialogue	• Line-by-line dialogue review • Does the dialogue resonate with you? • What would you change?
Focus group 8 (District of Columbia only)	General feedback and gameplay	• Extended gameplay • What are your general impressions? • What do you like about the game? What do you not like? • Would you play this game?

Each focus group session was audio-recorded and transcribed verbatim, omitting all identifying data. Transcribed documents were downloaded onto a password-protected computer for data analyses. NVivo 11 was used to begin the open coding process and the hierarchical coping model–guided analysis as themes emerged. Findings were shared with the game development team throughout the process to inform game development and refinements.

Results

Participants

In total, 86 youths identifying as African American aged between 15 and 21 years participated in this study. Overall, 6 individuals, 3 males and 3 females, participated in the youth advisory board. One female member withdrew because of school and work conflicts after the first session. Finally, 26 youths participated in usability testing, and 54 individuals, 23 from AL and 31 from DC, participated in focus groups. A total of 8 focus groups were held in DC, 7 were held in AL with the LGBTQIA group, and an additional 7 were held in AL with the LGBTQIA status-unspecified group.

Regarding focus group participants, half of the participants (27/54) identified as male and 30% (16/54) identified as LGBTQIA. Most participants, 67% (36/54), were engaged in some kind of employment, and 65% (35/54) of the participants were in high school. Moreover, 35% (19/54) of the participants reported never playing video games, whereas 22% (12/54) of the participants reported playing games daily. Two-thirds of the participants (36/54) reported a history of sexual activity. Among participants with a history of sexual activity, 64% (23/36) reported using a condom during their most recent sexual encounter and 72% (26/36) had been tested for STIs at least once. Complete demographics and descriptive information are available in Table 2.

Table 2. Demographics, gaming habits, and sexual history of focus group participants.

Participant response	Value, n (%)[a]
Sex	
Male	27 (50)
Female	26 (48)
Trans female	1 (2)
Age (years)	
15	5 (9)
16	7 (13)
17	10 (19)
18	14 (26)
19	6 (11)
20	8 (15)
21	4 (7)
Identify as lesbian, gay, bisexual, transgender, queer/questioning, intersex, or asexual	
Yes	16 (29)
No	36 (67)
NR[b]	2 (4)
School status	
High school	35 (65)
College	18 (33)
Not in school	1 (2)
Employed	
Yes	36 (67)
No	18 (33)
Videogame play frequency	
Never	19 (35)
1-2 days per week	12 (22)
3-4 days per week	7 (13)
5-6 days per week	3 (6)
Everyday	12 (22)
NR	1 (2)
Ever sexually active	
Yes	36 (67)
No	15 (28)
NR	3 (6)
If yes, age at first sex (years)	
<11	1 (3)
11	3 (8)
13	4 (11)
14	6 (17)
15	8 (22)
16	6 (17)

Participant response	Value, n (%)[a]
17	4 (11)
18	2 (6)
NR	2 (6)
Condom use during last sex	
Yes	23 (64)
No	11 (31)
NR	2 (6)
Ever used condoms	
Yes	32 (89)
No	2 (6)
NR	2 (6)
Ever tested for STIs[c]	
Yes	26 (72)
No	9 (25)
NR	1 (3)
Ever had an STI	
Yes	5 (14)
No	29 (81)
NR	2 (6)
Number of sex partners now	
0	9 (25)
1	22 (61)
2	1 (3)
4	2 (6)
Number of sex partners in the last month	
0	5 (14)
1	20 (56)
2	3 (8)
4	2 (6)
5	2 (6)
>5	1 (3)
NR	3 (8)
Number of sex partners in the last year	
0	1 (3)
1	14 (39)
2	6 (17)
3	3 (8)
4	4 (11)
5	2 (6)
>5	1 (3)

Participant response	Value, n (%)[a]
NR	5 (14)

[a]Some percentages do not add up to 100 because of rounding.

[b]NR: not reported.

[c]STI: sexually transmitted infection.

Youth Advisory Board: Initial Prototype Development

Participants in the youth advisory board informed the design and development of the prototype SAAFE game. The main contributions of the youth advisory board are described below.

A *dating simulation game* was the preferred game concept. The research team presented 3 other choices to the youth advisory board: an American Idol or rap storybook, a professional athlete role play, and Game of Life board game. Members quickly and unanimously expressed preference for the dating simulation game. They were energized about creating their own character and making decisions through simulated real-life situations. The research team also presented minigames to embed within the game to enhance player engagement. Members liked all the games, which included *STI Shooter*, *Condom Run*, and *Fact Pop*.

Youth advisory board members wanted *characters that were realistic and customizable*. When asked about character design, they did not want cartoons and preferred characters that reflected their own ages. Characters should have different body types and skin tones, with many options for customization through clothing, tattoos, and accessories.

Members wanted *realistic settings, situations, and dialogue.* They preferred an urban setting and rejected settings they interpreted as *rich* or that seemed too perfect. The research team introduced options for situations and dialogue, and again, they wanted it to be as *real* as possible, often rejecting attempts at humor and preferring language they use in their everyday lives.

Youth advisory board members recommended that *instructions be part of game play*. Initial game instructions were tedious and too long and used words unfamiliar to them. Members would skip past them and *figure it out* as they played. They also pointed out that the meaning of status bars was unclear. For example, if the fatigue bar was full, members were not sure if their character was tired or well rested.

Members recommended *more sexual health education* in the game. They enjoyed game play but expected to learn more. They recommended that the pop-ups and dialogues deliver more information.

All youth advisory board feedback was incorporated before initiating usability testing of the SAAFE prototype.

Usability Testing of the Initial Prototype

According to a review of usability studies, 20 participants are sufficient to identify at least 95% of existing usability problems for a prototype [23]. Overall, 26 participants completed the SAAFE prototype usability testing and 23 completed the SUS survey. SAAFE's average SUS score was 77.7, which is higher than the average SUS score of 68 [24]. A SUS score of 80.3 or higher would place a game in the top 10% with regard to usability and is the point at which a user would recommend a game to a friend [25]. This benchmark score is within SAAFE's average score margin of error.

In addition, 25 of the 26 users responded to the 4 additional questions and agreed or strongly agreed that "I would recommend the SAAFE game to a friend" and "Overall, I am satisfied with playing the SAAFE game," with mean scores of 4.4 and 4.32, respectively. "I would consider downloading the SAAFE game to play" had an average score of 3.92, and "I learn a lot about STIs using the SAAFE game" had an average score of 3.96. These scores approached the goal score of 4, indicating that participants on average agreed with these statements or felt neutral.

Focus Group Findings: Game Development

The promising usability findings for the SAFFE prototype justified additional game development. Focus groups yielded the following key insights: offer extensive opportunities for avatar customization, including sexual orientation; create realistic and relatable storyboards; strike a balance between education and entertainment; use current technology that is as sophisticated as other games; allow youths to experiment and experience the consequences of their actions through storyboards; and include elements of competition and game-play incentives. A summary of the main themes is provided in Table 3.

Table 3. Themes emerging from focus groups regarding the game development.

Theme and its description	Representative quotes
Realistic	
Participants wanted the game to resemble the real world as much as possible	• "The whole point is to educate about what type of things go in your real life. It needs to be realistic." • "I feel like it's a small world right there." • "If you could add like a moving like...moving items...like a car driving around...add movement and to make it realistic...Maybe a bird or a plane...in the distance that will be good."
Relatable	
Participants wanted to relate to the language, situations, and characters	• "Also may be like adding stuff about like the LGBT community...LGBTQ community as well cuz...it seems very heterosexual in there." • "You should be able to pick the person who you want to be and not be just the generic." • "This is just an idea...But if he gave people the option to customize their own avatar basically...they're going to want to do it cuz it's like it's them...they can be who they want and they can let...you know they can learn more...But if you give them a random person...they will be like I didn't want that person...if it is a dude...a 30 year old girl will be like I don't want a dude...I am not dude." • "I also think some the language that they were using is a little bit like make me wanna roll my eyes a little bit like the way that they were talking to the...the narrator was talking to us like I don't know I can't remember what he said exactly but some of the stuff we were like what...I did not feel like authentic."
Customizable	
Participants wanted the ability to choose the gender, appearance, sexual orientation, and personality of the avatar; the type of community; and the education that they would be exposed to	• "If we had a really short hair option for girls." • "I just like for at least there to be a lot of options for dark skin." • "I think that when you have that at such a young age, they're not going to think anything of it and I think it is more likely to reinforce that dialogue is something that is acceptable."
Entertaining	
Participants preferred less text, more audio, and more entertainment to maintain engagement	• "The information that they were giving were really good...I think that there needs to be a little bit more fun though cuz I think it's like someone...wouldn't play." • "Even though like it is important information like you can shorten it for fun because it would be bored." • "Ya coz there is a lot of reading seems unnecessary."
Experiential	
Participants desired to experiment with high-risk behaviors and experience consequences of those behaviors	• "I think there should be a little bit of a scare in the game." • "If you get pregnant, it's just like game over." • "In real life, you can't go back, but in this game, you can learn." • "If you die you're going to be mad, you're going to be mad, but it's like you know you did that Victory Royale...you will be like I did it...I got it."
Modern technology	
Participants reported that they are accustomed to having many high-quality, high-functionality videogame options and would be unlikely to endure a game that was perceived to be outdated or difficult to use	• "You know video games are like really realistic now and so if you're trying to get [early teens] to want to pay attention to it, you're going to want something that's going to catch their eyes. If it is something like [school], they are going to just keep tapping until it is over." • "Because you don't, you don't want to make this whole game and go through this whole hassle and people are just tapping tapping and getting these coins and it's all for nothing."

Customization was a frequent topic of conversation and a high priority for focus group participants. Participants wanted their game avatars to better represent themselves. They wanted to choose the gender, appearance, clothing, sexual orientation, and personality of their avatar. Focus group participants specifically recommended offering a variety of skin tones, facial features, hair colors and styles, clothes, head coverings, jewelry, and props. Participants that identified as LGBTQIA requested gender-neutral options and elimination of binary options. Customizing the community—urban or suburban and high income or low income—was also suggested. Nearly all participants responded well to location-specific information about sexual health sites where they could get STI testing or free condoms, among other services. In addition, there was a discussion about customization of content for different age groups. For example, many older adolescent participants wanted to see vivid pictures of STIs but thought that might not be appropriate for younger teens. They suggested different game versions for different age groups.

Achieving a *realistic and relatable* game was a high priority for participants across focus groups. According to participants, the virtual world in the first version of the game looked like a *rich neighborhood* and unlike their own urban neighborhoods. They also expected the health center to look more like an emergency room, which was perceived to be a more routine place to obtain health care. The virtual world also needed more locations. Suggested locations included a restaurant, store, mall, friend's house, hotel, place of employment, library, school or college campus, dorm room, sports arena, movie theater, concert, club, bar, house party, and sex party.

Language, situational relevance, and dialogue proved to be highly nuanced and variable depending on the geographic location. For example, the slang term *lit* (meaning *exciting* or *excellent*) was agreed upon in both locations. *Mumbo* sauce (a condiment) is most popular in DC and raised questions in Birmingham. Both groups felt that baking a cake was not relatable, so it was swapped with making a pizza. In addition, early focus groups felt that dialogue with nonplayer characters was too short and that sexual proposals were too abrupt. Participants wanted real-life relationship building to be reflected in the game, which was further developed with dialogue and expanded storylines. In addition, 1 group discussed the importance of using language that discusses sex and sexual behavior in a way that is a matter of fact, positive, and not shaming. Some felt that the game assumed emotional intimacy in sexual relationships, although in reality, that is not always the case.

The appeal for *incentives and competition* in the game was nearly universal. All groups recommended that storylines include rewards for safe, healthy behaviors and consequences for high-risk behaviors. They suggested the ability to make and spend money within the game, perhaps for avatar enhancements such as a greater range of hairstyles. Some participants wanted to invite and compete with other players and to share their scores on social media. Minigames were offered as a way to earn and use *currency*. The minigames are sexual health themed and intended to be entertaining more than educational so that players stay engaged. An arcade was added featuring a range of minigame options to keep the players engaged and to earn money for use in the game.

Focus groups universally desired to *experiment* with high-risk behaviors and experience the sometimes unpleasant and difficult consequences of those behaviors. According to the youth, experiencing harsh consequences of risky behaviors in the virtual world would facilitate learning that could be applied to the real world. It would enhance the game's realism as well. One group suggested poor appearance or death as an outcome if you drink too much or do not get STI treatment. Participants were eager to replay a scenario so that they could choose a different behavior and see how the outcomes changed.

The youths expected the SAAFE technology, functionality, and graphics to be *modern and sophisticated.* They reported that they are accustomed to having many high-quality, high-functionality videogame options and would be unlikely to endure a game that was perceived to be outdated or difficult to use. They expected character animations—such as walking and dancing—and graphics to be more realistic and novel. One participant requested "maybe a bird or a plane in the distance." Nearly all participants expected music and audio features.

Discussion

Principal Findings

The main findings of this study were that a sample of African American youth in DC and AL preferred a dating simulation game that allowed experimentation with high-risk behaviors and that was customizable, entertaining, educational, realistic and relatable, incentivized and competitive, and modern and sophisticated. The SAAFE game was developed in partnership with the youth, and the youth found the SAAFE game to be highly usable.

Sexually Active Adolescent–Focused Education Game

Findings from focus groups led to the refinement and development of the final SAAFE game described here. The SAAFE game centers on visiting different locations in the virtual world and interacting with other nonplayer characters to build relationships and have intimate encounters. In response to focus group findings, 7 sexual health–themed storylines, or *missions*, were developed. Each mission represents a content area with learning objectives. Missions can be played sequentially or randomly. The first storyline *New Kid on the Block* introduces the player to the game and discusses the use of condoms and dental dams. The second storyline *Getting Tested* centers on STIs: transmission, health impacts, symptomology, testing modalities, and treatment, and a health care visit is modeled. *Making PrEParations* discusses the transmission, natural history, and treatment of HIV/AIDS and the use and benefits of pre-exposure prophylaxis (PrEP) in preventing HIV/AIDS. Storyline 4 *Just Say Yes or No* teaches about sexual assault, coercion, and incapacity and models sexual consent. Storyline 5 *Use It* centers on condom negotiation. Storyline 6 *All Romance* simulates relationship building and healthy communication about sex. The final storyline *Sex, Drugs, and Rock N' Roll* reviews the impact of substance use on sexual behaviors. Subthemes that run across multiple storylines include behaviors that mediate STI risk; abstinence and limiting sex partners; accessing health care; and responsible technology use, including sexting and pornography.

Findings emphasize the importance of players having the ability to customize their avatar's appearance and sexual orientation (see Figure 2 for a screenshot of character design). To improve the delivery of game-play instructions, we followed focus group guidance and oriented players to game features as part of the first mission (see Figure 3 for a screenshot of the Studenton city map). Game settings were developed based on focus group suggestions, including different school locations (cafeteria, homeroom, and sex education classroom) and city locations (movie theater, clinic, gym, store, video arcade, house party, and home; see Figure 4). As players interact with nonplayer characters, they are asked to select responses and behaviors that become increasingly sexually intimate and potentially high risk. As desired by our participants, healthy behaviors and learning are rewarded with coins and increases in health and attractiveness and relationship meters, whereas unhealthy behaviors are discouraged through decreases in the same meters. Undesirable outcomes such as STI acquisition, breakups, and loss of friends also occur in response to unhealthy behaviors (see Figure 5 for a screenshot of dialogue with a nonplayer character at home).

Delivery of educational content is consistent with focus group preferences. Players attend sex education class and converse with elders for more traditional didactic information exchange (see Figure 6). They can elect to view posters and videos that are located throughout Studenton. Pop quizzes, pop-ups, and links to outside resources are also scattered throughout the game (see Figure 7), and the arcade includes a sexual health trivia minigame (see Figure 8). Learning and skill building also occur as players move through the storylines and experience the rewards or consequences of their actions.

Figure 2. Screenshot of character design.

Figure 3. Screenshot of Studenton city map.

Figure 4. Screenshot of the clinic.

Figure 5. Screenshot of dialogue with a nonplayer character at home.

Figure 6. Screenshot of sex education class.

Figure 7. Screenshot of a pop quiz.

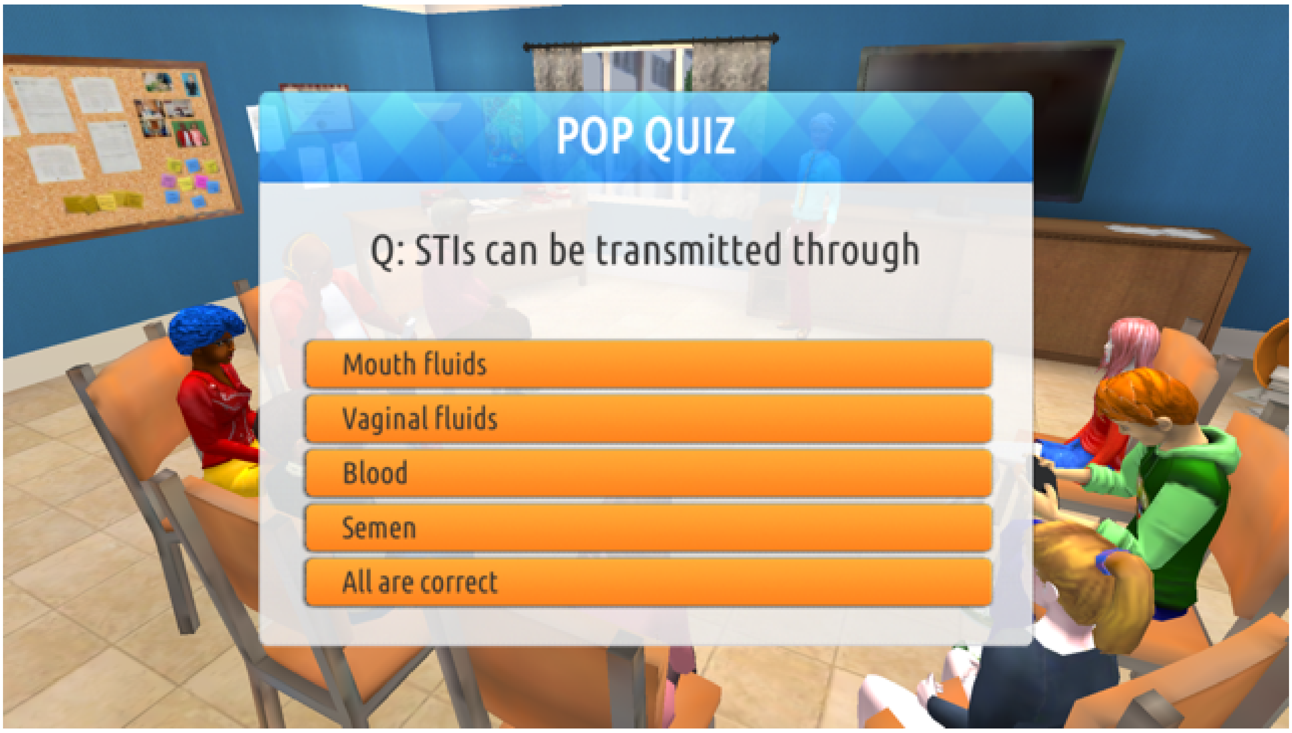


Figure 8. Screenshot of the arcade.

The mobile elements of SAAFE provide opportunities to customize content to local communities and specific audiences. For example, a link to or listing of local resources that provide sexual health care services and free condoms can be embedded. The legal status of sexual health services—for example, the age at which youths can consent to STI testing without parental involvement—varies geographically, and this information may be customized in the game. Videos and infographics embedded in the game can be swapped to meet the educational needs of specific audiences. This feature allows SAAFE to be useful and valuable to a multitude of entities, such as schools and health centers, and across geographic locations.

Creating and fostering community-engaged research with African American youth was critical to the successful development of the SAAFE game. The initial high usability index was a direct result of the partnership with the youth to ensure the game was not only relatable but also fun. This study has further elucidated how community-based participatory research can enable a transfer of knowledge and skills between the community and academic scientists. Indeed, youths participating in this project were highly engaged and committed and contributed sophisticated and nuanced insight. Adopting an Agile game development methodology also proved invaluable. Editing and developing the game between focus groups allowed participants to systematically review our progress. This interactive approach allowed the design team to collaborate effectively and ensure SAAFE appropriately reflected the feedback from focus groups.

Regarding theoretical frameworks, SAAFE applies SCT and PST by presenting information, modeling behaviors, and allowing players to experiment with behaviors that lead to desirable and undesirable outcomes. The youth are provided with engaging and educational pop-ups, quizzes, videos, and links to outside resources. Avatar-based realistic scenarios task youths with making sexual health decisions, and they virtually experience the outcomes of their decisions. Unhealthy behaviors may result in STIs, pregnancy, or the end of relationships. Ideally, players will develop self-efficacy, self-regulation, and problem-solving skills with regard to sexual health behaviors that will translate to the identification and adoption of those behaviors in real life.

Challenges and Lessons Learned

The sexual exposures and learning needs of youths aged 15 to 21 years are quite different. The information was novel, yet sometimes overwhelming, for younger youths, whereas older youths appreciated more detail and nuance but were already familiar with much of the information. Greater age specificity may be beneficial. Technology today is sophisticated, and the youth have many game and entertainment choices. Keeping pace with their high expectations and competing to win their attention will continue to be a challenge as long as a gap remains in research and development of commercial entertainment and serious game products.

Striking the right balance between education and entertainment was complex. Youths will engage more meaningfully with the game if they are entertained, yet the game is intended to be educational, and the youth expect to learn something. They expressed frustration with an imbalance either way. The game in its current form does not contain all educational content that we would have liked, most notably, contraception. Our team plans to develop reproductive health themes with next steps and additional resources.

Developing a game that is both customizable to the user while also being relatable and relevant to the larger demographic group proved challenging. We learned that it was easier to develop dialogue and content regarding facts. It was harder to develop dialogue and content to cultivate intimate communication skills and obtaining sexual consent. Dialogue, in particular, required many iterations. Geographic variations in language, culture, and access to health care led the team to adopt more generic language and information at the cost of specificity. The option to customize the game to different regions of the United States via a built-in dialogue engine mitigates this concern.

Thoughtful use of language was key. It was important to discuss sex and sexual behaviors in a way that is trauma informed, direct, nonjudgmental, and nonshaming. Youths also preferred language that was familiar and realistic. The development team desired language that was scientifically accurate and attentive to the psychological and emotional impact of words. This was perhaps the most complex aspect of developing SAAFE.

By modeling behaviors and conversations that are healthy and respectful, this game is part of a solution to contemporary social problems such as sexual assault and marginalization of persons living with HIV. We endeavored to counter stereotypes and include groups that have historically been excluded, including women, people of color, and LGBTQIA individuals. Participants in this project defied stereotypes that the youth are ill informed, reckless, and thrill seeking. On the contrary, youths desire to be responsible and healthy. The final game ensures to represent the youth in a manner that is accurate and respectful.

Implications

SAAFE is a highly usable mobile game that effectively engages African American youth to learn about and simulate healthy sexual behaviors. Further research, in the form of a larger randomized control trial, is currently underway to evaluate the game's ability to deliver health education, promote condom utilization, and prompt the youth to seek STI testing and treatment. Secondary outcomes of interest include PrEP knowledge and sexual consent knowledge, attitudes, and behaviors. Future versions will also include comprehensive contraception content.

Our Agile and community-based participatory research methodologies can be applied to the development of other serious games, particularly those of the simulation or role-play genres. Our results and lessons learned are also generalizable to serious game developers.

The initial findings suggest that SAAFE has the potential to help meet the need for innovative approaches to sex education and that SAAFE offers an opportunity to augment more traditional didactic sexual health education in an effort to promote healthy sexual behaviors and reduce the burden of STIs among African American youth.

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Conflicts of Interest

LP discloses participation in the Diclegis Speakers Bureau for Duchesnay Pharmaceuticals. Other authors have nothing to disclose.

Multimedia Appendix 1
Powerpoint presentation of study highlights with screenshots.
[PPTX File , 11999 KB - games_v8i1e16254_app1.pptx]

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Abbreviations

AL: Alabama
DC: District of Columbia
LGBTQIA: lesbian, gay, bisexual, transgender, queer/questioning, intersex, or asexual
mHealth: mobile health
PrEP: pre-exposure prophylaxis
PST: problem-solving theory

SAAFE: Sexually Active Adolescent–Focused Education
SCT: social cognitive theory
STI: sexually transmitted infection
SUS: System Usability Scale

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Review

Design Strategies for Virtual Reality Interventions for Managing Pain and Anxiety in Children and Adolescents: Scoping Review

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Abstract

Background: Virtual reality (VR) technology has been explored in the health sector as a novel tool for supporting treatment side effects, including managing pain and anxiety. VR has recently become more available with the launch of low-cost devices and apps.

Objective: This study aimed to provide an updated review of the research into VR use for pain and anxiety in pediatric patients undergoing medical procedures. Specifically, we wanted to gain an understanding of the techniques and goals used in selecting or designing VR apps in this context.

Methods: We performed a scoping review. To identify relevant studies, we searched three electronic databases. Two authors screened the titles and abstracts for relevance and eligibility criteria.

Results: Overall, 1386 articles published between 2013 and 2018 were identified. In total 18 articles were included in the review, with 7 reporting significant reduction in pediatric pain or anxiety, 3 testing but finding no significant impact of the VR apps employed, and the rest not conducting any test of significance. We identified 9 articles that were based on VR apps specifically designed and tailored for pediatric patients. The findings were analyzed to develop a holistic model and describe the product, experience, and intervention aspects that need to be considered in designing such medical VR apps.

Conclusions: VR has been demonstrated to be a viable choice for managing pain and anxiety in a range of medical treatments. However, commercial products lack diversity and meaningful design strategies are limited beyond distraction techniques. We propose future VR interventions to explore skill-building goals in apps characterized by dynamic feedback to the patient and experiential and product qualities that enable them to be an active participant in managing their own care. To achieve this, design must be part of the development.

(JMIR Serious Games 2020;8(1):e14565) doi:10.2196/14565

KEYWORDS

virtual reality; distraction; pain; anxiety; children; adolescents; design

Introduction

Background

In recent years, virtual reality (VR) technology has been explored in the health sector as a novel tool for supporting and monitoring treatment [1]. This increased interest in VR reflects recent advancements in commercial VR headsets (eg, Oculus Rift by Oculus VR, LLC) and mobile VR capabilities (eg, Samsung Gear VR by Samsung Electronics Co), leading to more affordable and feasible implementation of VR in health care. This use of VR in health care was pioneered by Hoffman et al, who, in the early 2000s, created SnowWorld, a VR gaming system that was able to reduce pain perception during burn wound care in both adolescent [2] and adult patients [3]. Since then, a number of studies have demonstrated the effectiveness of VR as a nonpharmacologic intervention for managing treatment side effects, such as pain, anxiety, or distress [4]. Typically, VR interventions involve a head-mounted display (HMD) worn by users, which allows them to experience 3D content (eg, videos and games) in an immersive virtual environment (VE). VR technology can afford health care providers greater capacity to improve patients' adherence to painful or distressing procedures while reducing the risk of the side effects associated with pharmacologic alternatives such as opioid dependency in pain management [5]. As a consequence, VR technology can improve patients' quality of life and satisfaction with care [6]. A recent systematic review and meta-analysis of 20 studies found evidence in support of significant reduction of acute pain in adults, with promising results for chronic pain [7]. Another review found similar evidence of efficacy for VR as an analgesic; however, it revealed a need for more research into mechanisms underpinning the success of VR apps to inform the design of future VR systems [8].

Pain and anxiety management using VR is often hypothesized to occur through distraction, by diverting a person's attention away from painful stimuli [9]. According to the neuromatrix theory of pain [10], cognitive, sensory, and affective inputs as well as factors influencing those, such as attention, can change pain perception and ultimately a person's response to it. Accordingly, by engaging the cognitive resources of a person in a task (eg, by watching or playing something through VR), offering them sensory stimulation (eg, visual and auditory), or offering them positive affective experiences (eg, enjoyment or success), limited capacity remains for the person to process or attend to pain [11].

Alternative applications of VR for managing pain and anxiety are explored through nondistraction techniques and tested in a range of settings from experimental to treatment (eg, fibromyalgia, burn wound care, and pediatric chronic headache) [12]. Instead of diverting a person's attention to unrelated tasks, those applications suggest that VR is effective when used to empower the user by allowing them to directly control their affective response to the painful stimuli. For instance, Loreto-Quijada et al [13] designed a VR app that enabled the user to manipulate unpleasant audio-visual aspects of a virtual object to create a more pleasant form and achieve a sense of calm and relief in the process. In another example, Shiri et al [14] created a virtual doppelgangers app to support the treatment of pediatric chronic headache. This involved a photorealistic capture of a user's facial expression combined with biofeedback to mimic their real-time emotional state. The app mediated an exercise of relaxation by bringing the user's attention to self and requiring them to focus on changing the virtual facial expression from a state of agony to calm [14].

The recent strategies for VR interventions in pain and anxiety management have yet to be systematically compared. This is needed to design VR experiences that are effective for use in health care and offer patients new opportunities for self-reflection and lasting impact on pain management capabilities. Beyond distraction therapy, there is currently little variation among VR strategies for pain and anxiety treatment [12]. VR technology is increasingly accessible to consumers who will be less impressed by the novelty of this technology and its power to *distract* in the near future. We will soon need better design strategies and the ability to predict the outcomes of VR intervention to help individuals with complicated health needs. Currently, though, there is limited understanding of the key design elements of effective VR experiences for health care. A model for understanding the strategies underlying VR for pain and anxiety management is needed to guide the design of successful VR interventions for patients across ages, health conditions, interaction constraints, and well-being goals. This study presents findings from a scoping review on VR for managing pain and anxiety in pediatric patients and synthesizes them to propose a model for designing such apps.

Objectives

This study followed a scoping review methodology specified by Arksey and O'Malley [15]. The scoping review aimed to investigate the breadth of the design and application of VR technology used for managing pain and anxiety in pediatric patients undergoing medical procedures. The outcome is summarized to identify a gap in the existing literature. We have chosen this population, as there is currently little evidence to support the systematic design of tailored VR apps. Recent research has indicated the increasing awareness of children about VR technology, as a survey of 1917 children aged 2 to 15 years in the United States found that only 18.9% (364/1917) of them had not heard of VR technology, and 43.9% (843/1917) of participants expressed extreme interest in VR [16]. Therefore, it is important to understand how we can leverage a technology well known to children for its potential health benefits.

The search was limited to articles published after 2012, the year the commercial Oculus Rift VR technology was first announced, as the launch of this device made VR technology readily accessible and available. The scoping review explored three questions: (1) What are the proposed intervention techniques and goals for VR apps to reduce pain and anxiety in pediatric populations? (2) What are the design considerations for VR experiences for reducing pain and anxiety around various medical procedures in pediatric populations? and (3) What tools and evaluation methods were used for assessing the efficacy of VR?

These questions are developed to inform the design of future VR apps for pediatric patients to reduce pain and anxiety. Recent literature suggested that although there is sufficient evidence on the efficacy of VR for reducing pain and anxiety, there is a visible gap in research on guiding strategies for designing such VR apps [8]. Through our first two research questions (RQs), we aim to understand the details on design directions and guiding principles of VR as an analgesic for pediatric population. The third RQ investigates how the designed apps are evaluated to reveal potential gaps in the assessment of the intervention and the outcomes. Findings from the scoping review were then synthesized and used for developing a model on the design elements that characterize VR apps for managing pain and anxiety.

Methods

Search Strategy and Eligibility Criteria

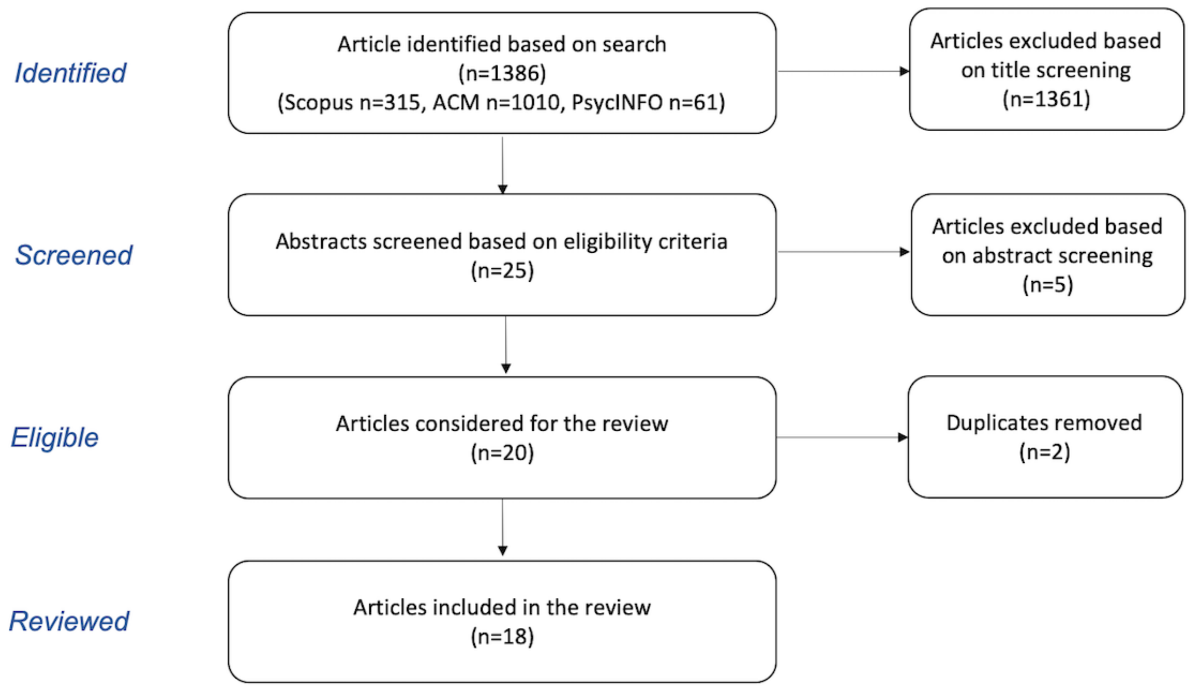
A literature search was undertaken between October 2018 and December 2018 in Scopus, Association for Computing Machinery (ACM), and PsycINFO, using combinations and variations of the following search terms: children, adolescent, virtual reality, distraction, and anxiety, stress, and pain. A detailed search strategy is provided in Multimedia Appendix 1. The search terms were chosen to align with the research aims and retrieve articles that use VR technology (bespoke design and commercial) in a wide range of contexts. The databases were chosen as those were more likely to include publications relevant to the RQs, given the exploratory nature of this research into the principles that informed the design of the VR apps. In particular, the ACM digital library includes publications from the fields of interaction design and human-computer interaction that are likely to explore bespoke VR designs. The inclusion of studies was then carried out as follows.

Peer-reviewed articles, published in English after 2012, and describing a VR intervention for managing or reducing, or both, pain, anxiety, or stress, or their combination, in children and adolescents (aged <18 years) undergoing medical procedures or treatment were included. Studies that investigated the use of VR for patient education, social skills training, or rehabilitation were not included. Studies that specifically addressed interventions for managing phobias were also excluded, as the underlying treatment is often long term and vastly different to the management of pain or anxiety. Papers were excluded if they focused on infants or children with intellectual disability, autism spectrum disorder, cerebral palsy, neurodevelopmental disorders or permanent cognitive disorders, or physical impairment. Those studies were excluded because the interventions would potentially involve strategies specific to a condition or a population group and may not be possible to generalize.

Study Selection

Overall, 1386 articles were identified. Two authors screened the titles and abstracts for relevance and eligibility criteria. If a decision could not be made based on abstract text, the full text was retrieved to make the assessment. After the title and abstract review, 20 articles were selected for a full-text review, of which 2 were duplicates and were removed. In total, 18 articles were included in the final shortlist for the scoping review. The elimination process is shown in Figure 1.

Figure 1. Flowchart of the literature screening and selection process. ACM: Association for Computing Machinery.



Evaluation Process

A data collection form was developed to extract the following study details: authors, year, medical procedure being addressed, sample size, age range, gender distribution, type of headset used, commercial product or bespoke design, description of VR app, description and design qualities of VR app (if available), study design, control group (if present), intervention goal, dependent variable, tools for measurement, and a summary of results. Those details allowed us to generate information relevant to the three RQs and specifically identify the intervention techniques and goals relevant to each VR app (RQ1), the design considerations for the app and the technology (RQ2), and trials and assessment details (RQ3). The key characteristics of the included studies are summarized qualitatively and tabulated in Multimedia Appendix 2.

Results

Scoping Review Results

Among the 18 articles that were reviewed, VR interventions for pain or anxiety were attributed to a wide range of medical treatment in children: magnetic resonance imaging (MRI) and radiology examinations [17]; wound debridement [18], specifically, burn wound [19-22]; venipuncture [23,24]; phlebotomy or blood draw [25,26]; cold pressor experiment [27]; preoperative care in hospital and anesthesia [28,29]; cancer treatment and chemotherapy [30,31]; injection, for instance, botulinum toxin [32]; and local anesthesia in dental care [33]. One study described the design of a VR app for broadly defined medical procedures, without specifying one [34].

Among those that specified a procedure, 7 articles addressed pain directly [18,21,24,26,33], whereas 6 articles addressed anxiety associated with pain during a procedure [20,22,23,25,32]. In addition, 4 articles addressed anxiety linked to a medical procedure [17,28-30].

The average age range specified for children and adolescents in the selected articles varied between 5 and 21 years, and one study reported participants aged between 8 and 57 years [18]. In terms of equipment, 10 articles used mobile phones to deploy VR apps on low-cost headsets, such as Google Cardboard, Samsung Gear, and View Master. One article described the design of a 360° video tour of the operation room and suggested that the outcome can be used on any platform [28]. Six articles used commercial high-end VR HMD, such as Oculus Rift and Sony HMZ T2. One article involved adolescents with burn injuries to head and, therefore, used a Kaiser Optics SR80a VR helmet mounted on a custom-built, articulated-arm tripod device to avoid any further wound damage because of wearing HMD. The details relevant to specific research questions are discussed in the following sections.

Research Question 1: What Are the Proposed Intervention Techniques and Goals for Virtual Reality Apps to Reduce Pain and Anxiety?

We reviewed the articles to identify any intervention goal (and relevant techniques to achieve those goals) that were specified or somewhat described and were used to select or design the VR technology. In total, 9 studies employed commercially available content, among which 4 studies used *SnowWorld*. As this game has been widely used in the past two decades, it is categorized as a commercial VR app. A total of 9 articles discussed a bespoke VR app specifically tailored for children and adolescent patient populations. We then classified the goals into three categories: those that aimed to distract the patient, those that aimed to strategically shift the patient's attention, and those that aimed to help patients build capacities to modulate pain through the use of the VR app. The studies in each category are discussed in the following paragraphs.

Several studies cited distraction as the main goal of the intervention; that is, attentional resources are temporarily engaged through VR, so there is limited capacity remaining for processing pain or anxiety-inducing stimulus. In its simplest form, distraction therapy involved entertaining media (eg, watching videos) [21,26,32,33]. Others used interactive games, such as SnowWorld game [18,24], Nintendo Wii *Sonic and the Secret Rings* game [27], and *Bear Blast* developed by AppliedVR [25]. The degree of interaction varied among those games; SnowWorld and Sonic and the Secret Rings games are played using a hand controller, whereas Bear Blast involves hands-free and gaze-based interaction (users gaze at a direction to move or perform in-game tasks).

A number of games were characterized as distraction therapy but cited more specific focus-shifting techniques for modulating pain or anxiety output. For instance, Birnie et al [30] suggested that enabling the user to maintain a point of focus on an object in front of them is important and designed a game where children can shoot rainbow balls at moving objects. Furthermore, Piskorz and Czub [23] used a Multiple Object Tracking paradigm to set priorities for cognition and shifting the player's attention from one virtual object to another during a venipuncture procedure. Players engaged with that task through head movement and gaze-based interaction.

Grishchenko et al [34] suggested a strategy to build further capacity in patients by creating a fixed reference point in the frame of view while facilitating deep breathing through game mechanics. Their gaze-based game, *Voxel Bay*, used audio command to make the game interactive and help players exhale more deeply to help prevent hyperventilation, a common side effect in children receiving painful treatment. Grishchenko et al [34] also suggested that relaxing audio can assist with regulating pain or anxiety and block anxiety-inducing noises of medical treatment. This point was also emphasized by Birnie et al [30] and Ko et al [22]. Finally, some articles used exposure to potentially distressing stimulus in a safe environment to alleviate fear and anxiety before the medical appointment. Liszio and Masuch [17] designed a game to introduce children to their MRI appointment. O'Sullivan et al [28] and Ryu et al [29] created 360° video tours of the hospital to familiarize children with anesthesia procedure before their operation.

Research Question 2: What Are the Design Considerations for Virtual Reality Experiences for

Reducing Pain and Anxiety Around Various Medical Procedures in Pediatric Populations?

We identified three clear groups of considerations that guided the design or selection of VR apps in review articles: creating a perception of autonomy and control for the user, providing a perception of safety by using familiar elements, and fostering empathy through the narrative. Further considerations linked to those groups also emerged, as discussed below.

An example of the first design consideration, autonomy and control, is the VR app developed by Birnie et al [30] to reduce needle-related anxiety in young cancer patients. The product was created through an iterative participatory design process with direct input from children, resulting in a game of treasure hunt and shooting rainbow balls at underwater creatures. Birnie et al [30] described principles, such as simplicity, interactivity, and aesthetic qualities such as colorful environment, which are important for mediating user engagement. Those principles seem to be relevant to the design of the product (the VR app). The researchers also suggested considerations important for creating a good experience for the user. For instance, they found that the ability to control the exploration within the game environment and to have fun impacts the user's sense of *presence* in the VE, which is crucial for increased attention to distractors and, therefore, the efficacy of the VR intervention [30]. Similarly, Ng et al [31] suggested that it is important that VR apps help cancer patients overcome boredom to manage treatment side effects. In another example, Gold and Mahrer [25] suggested that product aspects such as the complexity of a player's in-game progress can keep children and adolescents engaged during procedural distraction by eliminating worry about their performance. Gold and Mahrer [25] used Bear Blast, a commercial game where the user controls a firing cannon in VE and enters a new level every 2.5 min. Similar to the VR app developed by Birnie et al [30], Bear Blast intends to facilitate experience aspects such as positive reinforcement of *experimentation and activity* [25]. The importance of experiencing a sense of empowerment and autonomy was also emphasized by Grishchenko et al [34] in their game Voxel Bay, an audio command–activated game where deep exhales (into a microphone) assist the player to move a boat in VE. To keep the player interested and, therefore, distracted, Voxel Bay employs a narrative whereby the player controls some elements of their adventure (through playing diverse short games) but also experiences surprise, as the clinician controls the overall game navigation from their remote control station [34].

The second design consideration, using familiar elements to elicit a sense of safety, was demonstrated in familiar product qualities or creating familiarity through the experience. Familiar product qualities were often linked to featured elements in VE, such as references to popular games (eg, Minecraft and Lego [34] or SimCity [31]). Creating familiarity through the experience then involved creating a precedence for the medical procedure, for instance, by locating the game in the hospital environment [17,28,29]. This type of familiarization aimed to eliminate cognitive appraisal of elements that may be perceived negatively by children and adolescents and allow them to safely prepare for their appointment at a convenient time and place.

The third design consideration pertained to creating comfort for the patient by fostering a sense of empathy in VE. A number of games employed in-game companion characters to achieve that. For instance, Grishchenko et al [34] allowed children to choose an animal character to accompany them on a journey, and Ng et al [31] designed a companion cow character in a virtual farm for cancer patients to care for during chemotherapy. Ng et al [30] argued that symbolizing hope and growth and providing everyday motivation within the game (to interact and collect rewards) can enhance a sense of well-being in players with life-altering conditions such as cancer and used metaphors such as growing vegetables to signify that. Overall, narrative elements were used in all bespoke apps that were purposefully designed for children and adolescents. Some examples included hunting for treasures along a journey [27,34]; adventure [22,30]; playful interaction with animal characters; farming vegetables [31]; and shooting snowballs [18,24] or rainbow balls [30], or cannons [25] at animated objects.

Research Question 3: What Tools and Evaluation Methods Were Used for Assessing the Efficacy of Virtual Reality Interventions for Pain and Anxiety in Children?

In all, 10 articles used some form of control group in testing (eg, baseline control); 7 of which were randomized controlled trials, with sample sizes ranging between 13 and 143 participants. Without the assessment of usability or user experience, there is little evidence on the impact of design choices on patient experience or ability to manage pain. Outcomes were not consistently or systematically assessed among the reviewed studies. In all, 3 papers described the design of a VR app but did not test the outcome [22,28,34]. Others used interview and focus groups [31] and feedback on the usability and experiences of users [21] or caregivers [32] and used that feedback to tailor the design to children's needs [30]. One article presented a case study with one participant [19].

Overall, 7 studies showed that VR interventions significantly reduced anxiety [29], pain [18,20,24,27], or both [23,25]; and 3 studies tested but found no significant impact of the VR intervention [17,26,33].

All studies that tested anxiety and pain outcomes used self-report, mostly, standardized anxiety (eg, State-Trait Anxiety Inventory for Children and Yale Preoperative Anxiety Scale), pain severity (eg, through Visual Analogue Thermometer and Adolescent Pediatric Pain Tool), and worry related to pain (Wong-Baker Faces Pain Scale) scales. In some cases, numeric scales were developed by researchers to measure pain, nausea, stress, or satisfaction. A number of studies relied on expert evaluation of observed pain indicators by using tools such as Faces, Legs, Activity, Cry, and Consolability [32]. One study [24] evaluated the impact of VR intervention on multiple aspects of pain: cognitive component (time spent thinking about pain), affective component (unpleasantness), and perceptive component (worst pain). Only one study combined self-report with physiological assessment of pain output through pulse rate [33].

Summary of Findings

A range of considerations were identified through our literature review that are important for creating bespoke VR apps for pain and anxiety management. These are summarized in Table 1 and include two categories of considerations for creating virtual reality apps: intervention considerations (underlined by three types of goals, namely distraction, focus shifting, and skill building) and design considerations. A close examination of the findings relevant to RQ1 and RQ2 reveals that some design considerations are specific to the product aspects (the VR app and the technology and its content), whereas other design considerations are specific to the aspects of experience that the patient might have as the result of interacting with the product (such as their emotional experience and enjoyment). Examples and articles relevant to each of those categories are provided.

Table 1. Classification of findings relevant to considerations for creating virtual reality apps for managing pain and anxiety.

Considerations	Examples	Articles
Intervention considerations		
Distraction	• Engaging the patient's attention through VR[a] content through entertaining videos or games, for example, *Sonic and the Secret Rings* (Nintendo Wii) and *SnowWorld*	Faber et al [18], Hoffman et al [19], Jeffs et al [20], Scapin et al [21], Atzori et al [24], Gold and Mahrer [25], Gerçeker et al [26], Chau et al [32], Al-Habibi et al [33]
Focus shifting	• Engaging the patient's cognitive resources through game-led tasks, for example, multiple object tracking	Piskorz and Czub [23], Birnie et al [30]
Capacity or skill building	• Engaging the patient in game-led activities to build capacities for self-regulation, for example, deep breathing in *Voxel Bay*	Liszio and Masuch [17], O'Sullivan et al [28], Ryu et al [29], Grishchenko et al [34]
Design considerations		
Product	• Tailoring simplicity and interactivity to improve control • Removing barriers to engagement to improve a sense of autonomy • Diversifying sensory inputs • Diversifying sensory output and stimulation • Improving sense of presence	Gold and Mahrer [25], Birnie et al [30], Ng et al [31], Grishchenko [34]
Experience	• Improving ability to attend to distractors • Creating a sense of safety through familiar design elements or familiarity with medical procedure • Incorporating narrative elements • Cultivating growth and motivation • Fostering empathy and compassion	Liszio and Masuch [17], Jeffs et al [20], Ko et al [22], Atzori et al [24], Gold and Mahrer [25], Sil et al [27], O'Sullivan et al [28], Ryu et al [29], Birnie et al [30], Ng et al [31], Grishchenko et al [34]

[a]VR: virtual reality.

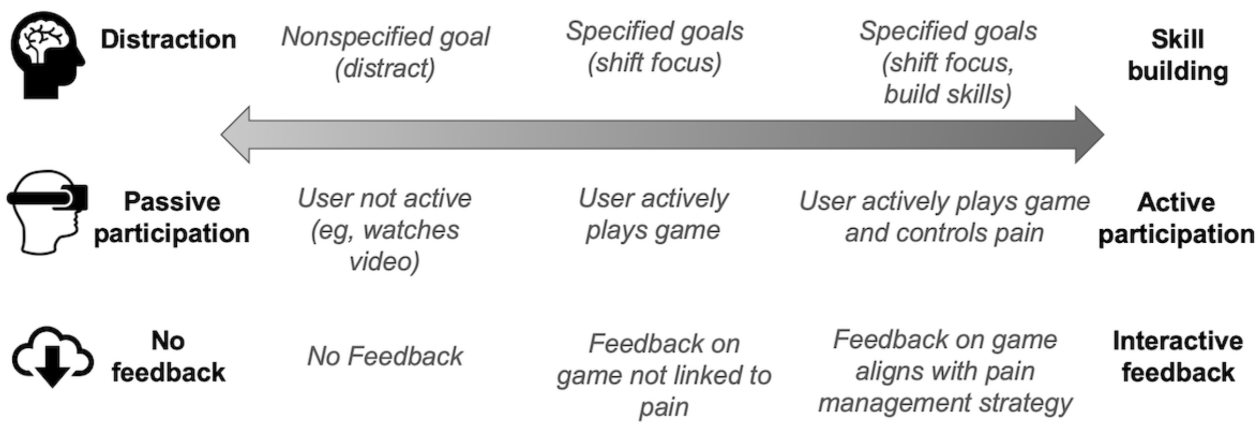
Product aspects for designing VR apps for managing pain or anxiety in children and adolescents can be achieved in several ways, for instance, by (1) tailoring simplicity and interactivity of VR for young users, taking into account aesthetic qualities that conform to the user's expectations and prior experiences with digital technologies (eg, colorful environment inspired from familiar themes); (2) removing barriers to engagement to allow young players to proceed in game regardless of their performance; (3) diversifying sensory input modalities in user-device interaction, for instance, by combining audio commands with gaze input to instigate a game action; (4) diversifying sensory stimulation, for instance, by incorporating music, to further divert attention from painful stimuli; and (5) improving immersion in VE by combining sensory (audio, visual, and tactile) and affective (eg, fun) experiences in active interaction with virtual objects in a game environment to help users be immersed in VR.

The experience aspects can be tailored in multiple ways, for instance, by (1) empowering users with the ability to attend to distractors through engaging features; (2) eliciting comfort and positive affect through interpersonal interaction (eg, doctors control some game elements) or familiarity (eg, familiar design elements and understanding medical procedure)—our review suggests that a full spectrum of human affect (eg, positive emotions such as pride) is not explored in many examples we reviewed, and there is scope for further investigation; (3) incorporating narrative elements (eg, treasure hunt); (4) enhancing motivation through cultivating personal growth (eg, introducing daily incentives such as caring for a garden); and (5) fostering empathy and companionship, for instance, through virtual companion characters in games.

These aspects, in combination with the intervention aspects (such as goals), can be used to characterize a VR intervention for mediating self-management of pain or anxiety. The intervention aspects include strategies informed by the three identified goals for managing pain and anxiety. Those may involve a varying degree of user engagement from passive participation (eg, watching a video, with no interaction and receiving no feedback) to active (eg, interactive games, providing interactive feedback to the user, which can align with a pain management strategy). We distinguish between distraction and focus shifting in VR, as the latter involves active participation in cognitive tasks with feedback to guide the user's interaction and consequently their response to pain. Typical examples of focus shifting in VR offer one or multiple *points of focus* for users (eg, multiple object tracking) within a game environment, for example, treasure hunt. Some VR interventions go even further, engaging the patient in active self-regulation, for example, relaxation through deep breathing in Voxel Bay [34]. Evidence on those types of intervention is scarce (*Voxel Bay* was not tested in a clinical trial), and more research is needed to examine the range and effectiveness of such interventions.

In an attempt to detail the relationship among the components of the holistic model, we propose a continuum to summarize the multitude of intervention strategies for managing pain and anxiety in VR, ranging from distraction to skill building, as shown in Figure 2. This elaborates further on patient experience and role (ranging from passive to active), depending on the intervention goal (ranging from distraction to skill building) and the VR product design (level of feedback provided to the patient).

Figure 2. VR interventions for pain and anxiety on a continuum; characterized in terms of patient experience and role (passive to active), VR design (feedback to user from none to interactive feedback) and intervention goal (distraction to skill-building).



Discussion

Overview

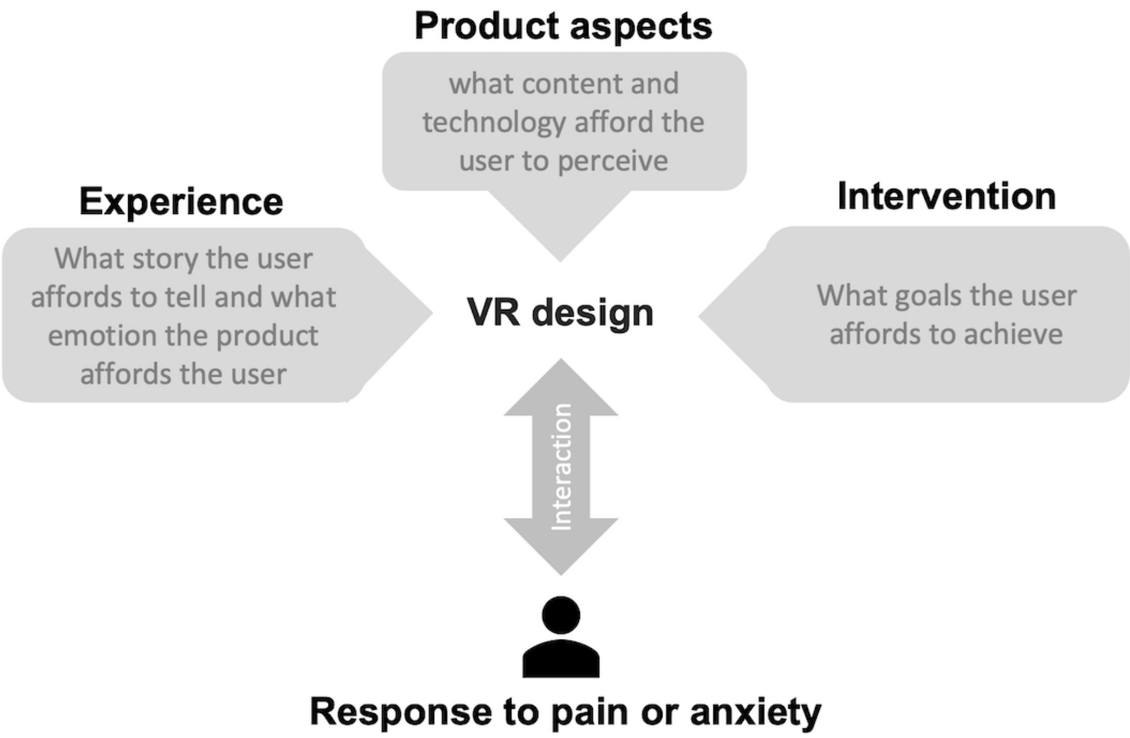
Through reviewing a selection of 18 articles that employed VR technology, we found a number of areas where this technology is currently administered to modulate pain and anxiety in children: acute (eg, wound care) and chronic (eg, cancer treatment) pain or anxiety, needle phobia (eg, blood draw), and procedural care (eg, MRI and preoperative care) in children and adolescents. We searched for goals and considerations to generate insight to support the design of future VR apps for pediatric patients. This resulted in two main contributions. The first is a classification of the range of intervention goals in pain management into distraction, focus shifting, and skill building. This classification is then used to inform our second contribution, a holistic model of considerations for designing medical VR apps.

A Holistic Model to Support the Design of Medical Virtual Reality Apps

The holistic model (shown in Figure 3) proposes that the way a VR product is perceived by the users (product aspects), combined with the experience and emotions it elicits (experience aspects), mediates intervention goals for managing pain or anxiety (intervention aspects). The model is unique, as it aligns a human-centered approach consisting of VR product and experience aspects with a medical approach consisting of intervention aspects appropriate for reducing pain or anxiety. Previous research has discussed elements of VR analgesia beyond distraction [12,13]; however, those fall short of exploring the design opportunities provided by our holistic model. The details and theoretical relevance of each aspect of the model are described in the following paragraphs.

Experience aspects subscribe to the definition of an experience, a multifaceted personal narrative, with a beginning and an end [35], that can be articulated retrospectively and characterized based on interactions, feelings, meanings, and actions [36]. In human-computer interaction research, experiential aspects are attributed to affect and human psychological needs. There are several approaches to defining psychological needs. At a basic level, Peters et al [37] propose fulfilling three needs suggested by the self-determination theory (autonomy, competence, and relatedness) as proxies for a well-being–supportive design. In a study on VR exercise platforms, Ijaz et al [38] found that two of those needs (autonomy and competence) strongly correlate with positive affect (eg, enjoyment) in immersive VR platforms for health and exercise. In technology-mediated experiences, affect (encompassing various constructs with feelings, such as emotions and moods) is often regarded as an integral part of an experience, and positive affect is central to enabling achievement of personal goals for well-being [36]. On the basis of the above, the experience aspects of VR for managing pain and anxiety can be described in terms of the narrative of the experience and emotions that are elicited through interaction.

Figure 3. A holistic model to support design of VR interventions for managing pain and anxiety.



Product aspects are described in terms of the user's subjective perceptions of the product content and technology. Hassenzahl et al [36] defined product aspects as how people perceive a product or translate its features (eg, screen and controls), material, style, and interaction form into qualities such as fun or complicated. Hassenzahl [39,40] suggested the way we perceive a product complements our experience of it and identified two main groups of product qualities that contribute to its experience. One group is pragmatic or instrumental qualities (eg, predictable, manageable, and simple) and refers to the judgment of a product's capability to support what we can do with it. The other group is hedonic qualities (eg, stylish and professional) and refers to how the product supports pleasure and ownership in use [36]. In this paper, we uncovered VR product qualities that are relevant to pain or anxiety management in the literature. For instance, immersion is an important aspect of VR products and defined as sensory stimulations linked to the perception of presence in VE, that is, feeling as if one is there. This was deemed important by some papers [30], as achieving a sensation of presence in VR can override our perception of pain or distressing stimuli and therefore results in better distraction during medical procedures [41]. Hedonic qualities include aesthetic, playful, and adventurous [22,30] or familiar [31,34].

Intervention aspects are linked to the intended health goals and well-being outcomes for the user. Although the ultimate goal for VR interventions in this study is pain or anxiety management, the strategy for achieving such goal may vary from simple distraction to active participation in a self-regulatory process. Liszio and Masuch [17] suggested that an intervention for pain and anxiety management might take a cognitive approach (ie, address the appraisal of the stimulus that is perceived harmful or stressful) or an affective approach (ie, provide an emotional coping strategy for the individual). Therefore, understanding those strategies through specific goals and subgoals provides a roadmap for the intervention and can guide practitioners and researchers in advising treatment regimen and configuring complex VR systems that support self-regulation.

Our proposed holistic model can be used as a lens to examine the trends and evidence of VR interventions. It can also be employed as a proxy to devise design strategies to achieve the intervention goals. There is currently no other model that puts those elements in perspective. As this model is based on evidence from our scoping review, it can be considered feasible for design and interdisciplinary examination of evidence in the fields of interaction design and medicine.

Finally, through a review of current methods for evaluating intervention outcomes in selected studies, we identified a lack of evidence on degrees, forms, and strategies of interaction suitable for the severity of pain and anxiety in medical treatments. Although VR is widely accepted as a viable distraction from pain, our review identified 3 studies (published between 2017 and 2018), where such distraction did not generate any significant difference in pain or anxiety. A closer look reveals that 2 of those studies relied on passive user engagement through videos to reduce pain and anxiety. We note that children are increasingly familiar with VR technology, and perhaps, a lack of technology novelty and interactive feedback is responsible for those failed interventions. A link between age and response to VR interactivity should be considered, as research has shown a significant increase in pain tolerance in children aged 10 to 15 years who used VR compared with younger children aged 6 to 9 years [20].

Limitations

A notable limitation in reviewed articles is a lack of assessment measures for establishing the efficacy of novel VR interventions for children and adolescents. Only 10 of 18 studies conducted testing or trials on the efficacy of VR apps. These studies consistently used self-report to establish the success of the intervention based on anxiety, pain severity, stress, or worry associated with pain variables. Only 1 study [24] addressed pain as a multifaceted experience with cognitive, affective, and perceptive components. This highlights a research gap on the impact of design elements (product or experience aspects) and strategy (distraction, focus shifting or skill building) on the pain or anxiety outcome, challenging the reliability of outcomes. Future research should use product, experience, and intervention aspects to describe the design and assess the outcomes in controlled trials and combine self-report with physiological indicators of pain and anxiety to determine efficacy. In addition, it is important to investigate differences between VR intervention goals (eg, distraction vs skill building) in relation to treatment outcomes. Overall, our observation leads us to believe there is a lack of interdisciplinary collaboration and research in relation to medical VR technology for pain and anxiety management, as a number of publications that involved a bespoke VR app did not present clinical testing, whereas the clinical trials consistently used commercial products and did not observe the impact of design on the intervention outcome.

Conclusions

VR has been used widely in the health sector and has been demonstrated to be effective for modulating pain and anxiety in a range of settings, including pediatrics. A scoping review of 18 papers published between 2013 and 2018 revealed that VR has been adopted as a viable intervention for managing pediatric pain and anxiety in a range of medical treatments. However, only half of the reviewed studies attempted to design the VR app specifically for the context it was intended for. Consequently, there are limited guidelines to inform the design of effective VR apps for supporting patients in the pediatric setting. We propose that a holistic approach to designing VR in health care involves consideration of product, experience, and intervention aspects. We also propose future VR interventions to explore skill-building goals in apps characterized by dynamic feedback to the patient and experiential and product qualities that enable them to be an active participant in managing their own care.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Search strategies used on databases Scopus, ACM and PsycINFO.

[DOCX File , 25 KB - games_v8i1e14565_app1.docx]

Multimedia Appendix 2

A summary of reviewed articles.

[DOCX File , 20 KB - games_v8i1e14565_app2.docx]

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Abbreviations

ACM: Association for Computing Machinery
HMD: head-mounted display
MRI: magnetic resonance imaging
RQ: research question
VE: virtual environment
VR: virtual reality

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Original Paper

Learning to Read by Learning to Write: Evaluation of a Serious Game to Foster Business Process Model Comprehension

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Abstract

Background: The management and comprehension of business process models are of utmost importance for almost any enterprise. To foster the comprehension of such models, this paper has incorporated the idea of a serious game called Tales of Knightly Process.

Objective: This study aimed to investigate whether the serious game has a positive, immediate, and follow-up impact on process model comprehension.

Methods: A total of two studies with 81 and 64 participants each were conducted. Within the two studies, participants were assigned to a game group and a control group (ie, study 1), and a follow-up game group and a follow-up control group (ie, study 2). A total of four weeks separated study 1 and study 2. In both studies, participants had to answer ten comprehension questions on five different process models. Note that, in study 1, participants in the game group played the serious game before they answered the comprehension questions to evaluate the impact of the game on process model comprehension.

Results: In study 1, inferential statistics (analysis of variance) revealed that participants in the game group showed a better immediate performance compared to control group participants (*P*<.001). A Hedges g of 0.77 also indicated a medium to large effect size. In study 2, follow-up game group participants showed a better performance compared to participants from the follow-up control group (*P*=.01); here, a Hedges g of 0.82 implied a large effect size. Finally, in both studies, analyses indicated that complex process models are more difficult to comprehend (study 1: *P*<.001; study 2: *P*<.001).

Conclusions: Participants who played the serious game showed better performance in the comprehension of process models when comparing both studies.

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KEYWORDS

business process model comprehension; business process modeling; serious games; learning; research design

Introduction

Background

The application of game designs and their related principles constitutes a promising approach to encouraging learning and to playfully imparting knowledge [1,2]. More specifically, this could mean integrating a game design and its principles into a nongame context (eg, administrative work). Among others, serious games have received attention as a potential alternative for fostering professional development by stimulating an active learning process [3]. By using specific design principles derived from video games (eg, competition, curiosity, and collaboration), serious games integrate these into a nongame context to improve motivation when completing or addressing complex or bothersome tasks [4]. Accordingly, there have been reviews and studies that investigated the potential impact of such games on learning and skill enhancement [5]. For example, Wouters et al [6] evaluated several game features (eg, role play) and outlined that serious games and their respective features can improve cognitive skills (eg, problem-solving). Furthermore, Von Wangenheim and Shull [7] demonstrated that serious games are an effective approach for learning, especially for the reinforcement of knowledge.

Owing to the increasing positive awareness of serious games, various disciplines (eg, education, health care, and business) have adapted the use of serious games according to their purposes [8-10]. Based on this, the computer science discipline that deals with the creation and understanding of process models is also suitable for the utilization of serious games [11]. A process model is a type of diagram that represents the procedures, workflows, and algorithms [12], but it specifically documents all steps, decisions, and involved persons needed to achieve a specific goal. Therefore, process models have been widely adopted in different domains (eg, computer science, and health care) [13,14]. In this context, business process models constitute an extension of process models, which are predominantly used in the field of business and industry for the documentation of respective business processes [15]. The creation of business process models (ie, business process modeling) and understanding them (ie, process model comprehension) are essential factors for enterprises to capture and work with their business processes daily [16]. In this context, the modeling and comprehension of processes and respective models are demanding tasks. Consequently, knowledge about the process to be modeled/understood, as well as respective expertise, is required to be able to use the advantages of business process models [17].

Knowledge in process modeling and the expertise to properly comprehend a process model are often acquired through work experience, formal training, or through educational institutions (eg, universities). Therefore, a proper education or training in process modeling must be ensured to understand how to model business processes correctly and, thus aim to create high-quality process models [18]. Furthermore, the capability to properly understand process models is accompanied by learning how to both create and model them. Vice versa, the inverse is only conditionally applicable; that is, learning to comprehend process models only fosters the ability to model processes to a limited extent [19].

In the context of our research, to foster the comprehension of process models, the application of serious games for training for process modeling and understanding offers promising opportunities to significantly improve them [20,21]. For process modeling and process model comprehension, specific research exists evaluating the potential use of serious games in this context. For example, a serious game approach with an emphasis on process enactment and a discussion about opportunities in the context of business process management has been elaborated on in a study by Herzberg and Kunze [22]. Vuksic and Bach [23] also gave suggestions about introducing a simulation game environment to foster an overall understanding of using business processes. Based on virtual environments, Ribeiro et al [24] introduced a serious game for teaching business process modeling, model comprehension, and process simulation. In turn, in a study by Aysolmaz et al [25], an office environment was virtualized using a three-dimensional virtual world to enable an immersive experience for improving process model comprehension. The results and insights obtained from a field study in which a serious game based on a business process model is used to familiarize employees with a complex process of a manufacturer were discussed in a study by Rosenthal and Strecker [26]. Finally, Mendling et al [27] discussed viewing characteristics of process modelers (eg, level of theoretical knowledge of modeling). Afterward, the characteristics that influence process model comprehension were investigated by taking gamification into account.

Beside expertise gained in process modeling and comprehension during the accomplishment of practical tasks, interestingly, many business analysts or process modelers learn more about business process modeling and their importance for enterprises in tertiary institutions (eg, universities) [28]. Nowadays, well-trained process modelers are crucial for enterprises to overcome many daily challenges. Understanding these models is also of utmost importance, as, for example, people need to know about their responsibilities and where to get relevant information from [29]. For example, enterprises must flexibly react to changes in the market. Therefore, they need to be able to align their business processes accordingly to satisfy technological and environmental evolutions or constraints. Thus, ensuring proper comprehension of process models through good education in the business process field should be a key factor for enterprises.

Objective

To address this and enhance our understanding of process model comprehension, this paper presents a serious game to investigate its impact on the comprehension of process models. In particular, the presented serious game teaches the essentials of the business process modeling standard Business Process Model and Notation (BPMN) version 2.0 [30] to foster the general comprehension of process models. Furthermore, it must be noted that the objective of the serious game is not conveying the subtleties of BPMN version 2.0 but rather creating a fundamental understanding of working with process models. Therefore, the serious game introduces core concepts for process modeling. It also teaches the most common modeling elements of BPMN version 2.0 and their precise meaning for the creation of proper process models, including correct comprehension of the used modeling elements. Overall, to evaluate the impact of the serious game on process model comprehension, the following two research questions are addressed in this study: (1) is the comprehension of process models directly after playing the serious game better in participants playing the game than in those who did not play, and does this depend on the model complexity; and (2) is the comprehension of process models four weeks after playing the serious game better in participants who played than in those who did not and does this depend on the model complexity?

Two studies were conducted to investigate the raised questions. For question 1, process model comprehension of the participants who played the serious game was compared to the performance of those who did not play the serious game. For question 2, exactly four weeks after conducting the first study, the performances of the same participants who played the serious game during study 2 but not in study 1 were compared with each other. Therefore, question 2 was concerned with whether the serious game fostered comprehension of process models at the follow-up study. Finally, for both questions, the level of process model complexity was considered to evaluate whether the learning process is affected by the complexity of the process models.

Methods

Tales of a Knightly Process

The serious game, Tales of a Knightly Process, tells the story of King Rex, the ruler of the kingdom Processia. Unfortunately, via a raven messenger, the king gets to know that his future princess, Calidia, was abducted by the Black Knight. With all his fervor, King Rex mobilizes all his troops to release his beloved princess from the Black Knight's claws.

The story of the serious game is divided into 3 acts, including a separate prologue and epilogue. Each act contains a set of levels in which a process model (expressed in terms of the BPMN version 2.0) has to be modeled for a specific situation (eg, a siege of the Black Knight's castle). In total, 13 processes have to be modeled as a BPMN version 2.0 process model while playing the serious game. In the beginning, simple processes have to be modeled, but as one progresses, the processes become more and more complex. In the first half of the serious game, basic process modeling elements (eg, activities) and constructs (eg, loops) of BPMN version 2.0 are introduced and explained via narration by the king. In the second half of the serious game, the previously learned aspects of BPMN version 2.0 and process modeling are mainly repeated. Furthermore, in the first half of the game, the modeling of processes is the main focus, while in the second half of the game, there is an emphasis on process model comprehension. For a better overview, the BPMN version 2.0 elements used in the game are explained:

- Activities: An activity is an atomic or nonatomic task and describes an executable step in a process (eg, place order).
- Event: An event indicates that something is happening in the process which affects its flow (eg, error detected).
- Gateway: A gateway allows for control as well branching, and merges the process flow (eg, decision points).
- Sequence flows: Sequence flows connect all elements in a process model and represent the direction of the flow (eg, choreography).
- Pool: A pool describes an independent (organizational) unit with clearly defined boundaries in a process (eg, enterprise).
- Lane: A lane represents concrete people, roles, or departments within a pool (eg, sales department).
- Subprocess: A subprocess allows the modularization of (complex) process models into smaller models to reduce the complexity and increase comprehensibility.

Serious Game Mechanics

The story is told with the use of dialogue from the perspective of King Rex (see Figure 1). To save his princess, the king must reach the Black Knight's fortress. On his way, he must prepare his troops, gather resources, and overcome dangers. Thus, these situations must be modeled in the serious game in terms of BPMN version 2.0 process models.

To continue the story, a process model must be created for each level, which is done using a separate process modeling environment (see Figure 2). In this environment, only specific elements are available, all of which must be used to complete the level. Therefore, these particular elements must be placed and connected as specified in BPMN version 2.0. After a process model has been created, it is checked to determine whether it is correct. Progress to the next level is made only with a correct process model. Otherwise, the process model must be adapted accordingly.

For further assistance during process modeling, the serious game provides scrolls that contain hints and additional information about previously learned BPMN elements and constructs (see Figure 3). Specifically, the use of elements and their respective meanings are described in more detail alongside an example of their use. The main focus of the serious game is on the imparting of knowledge about BPMN version 2.0 and how to use it for process modeling, with an addition goal of fostering the comprehension of process models. However, the serious game also emphasizes the added value of curiosity and competition to hopefully induce higher motivation and an enhancement of the learning process. Therefore, the serious game offers additional concepts from video games, such as resource management and item crafting (see Figure 4). Furthermore, the serious game is designed to have a supporting narrative storyline, as the story is tailored by the choices made therein, thus increasing replayability.

Figure 1. Storytelling of the serious game.

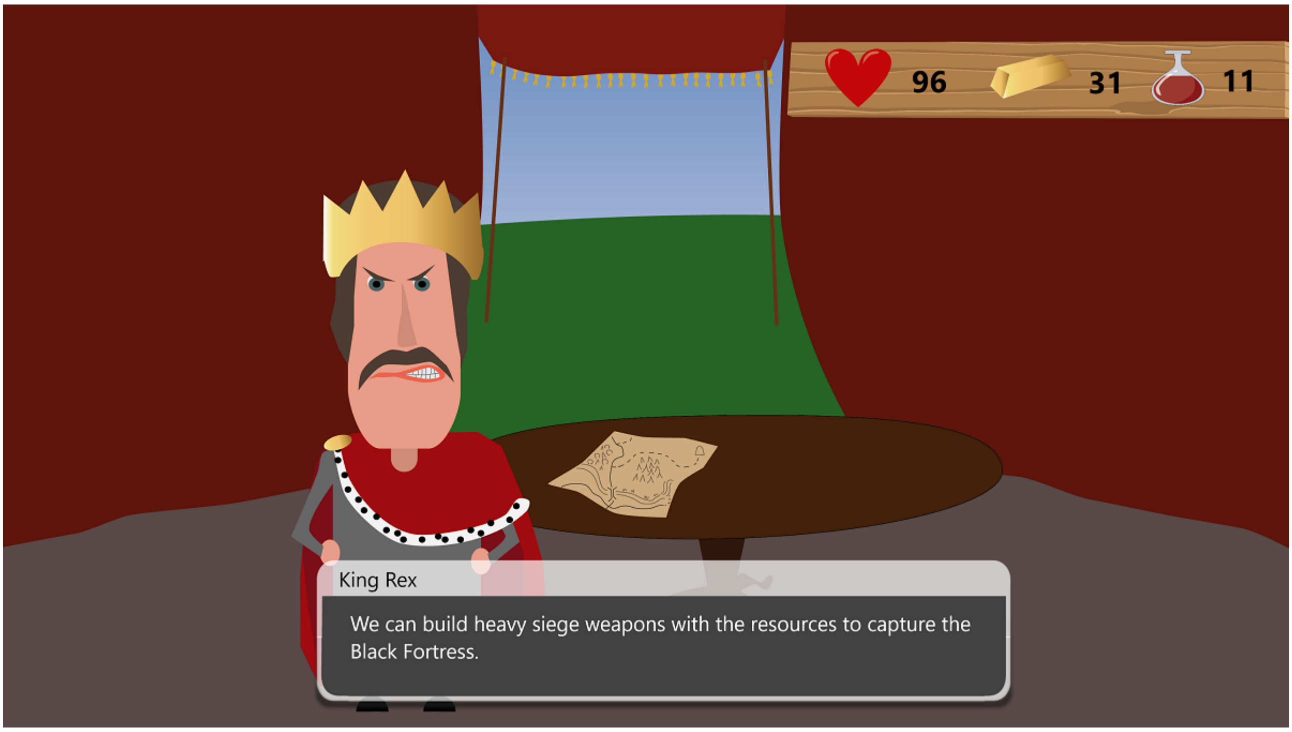


Figure 2. Process modeling environment.

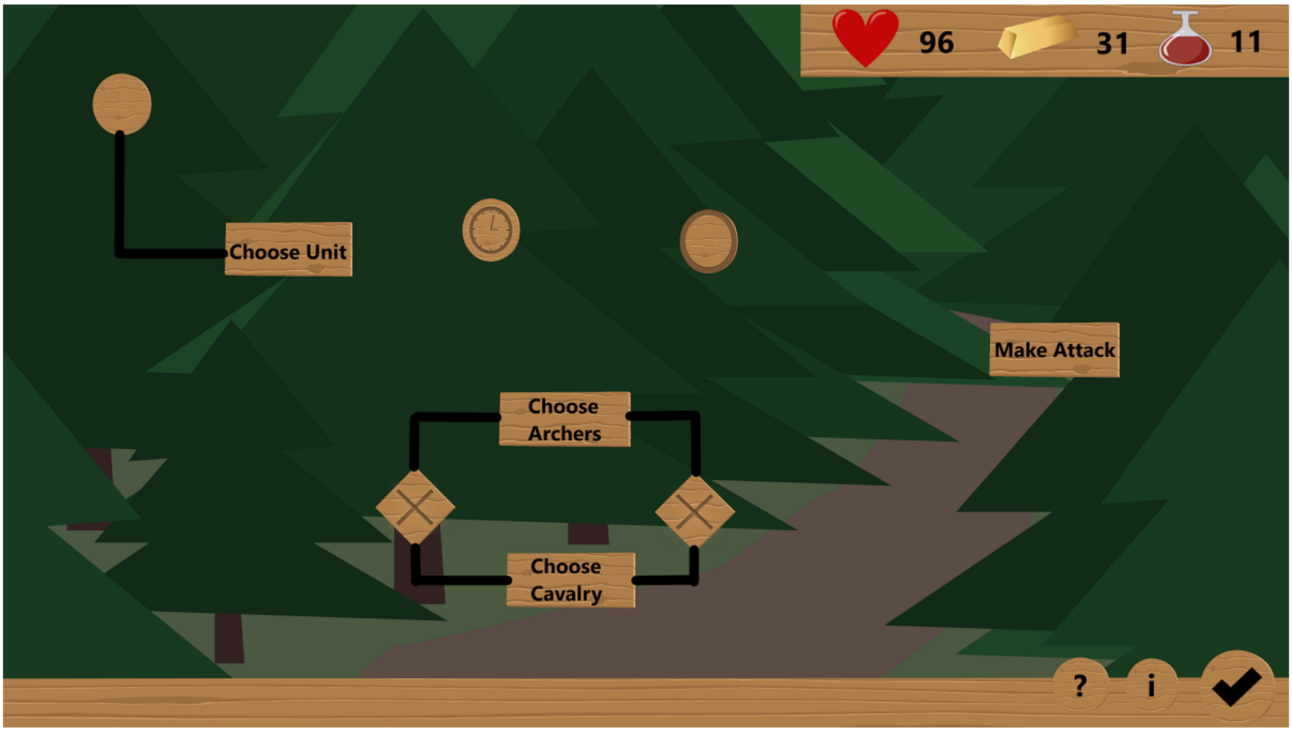


Figure 3. Description and help text.

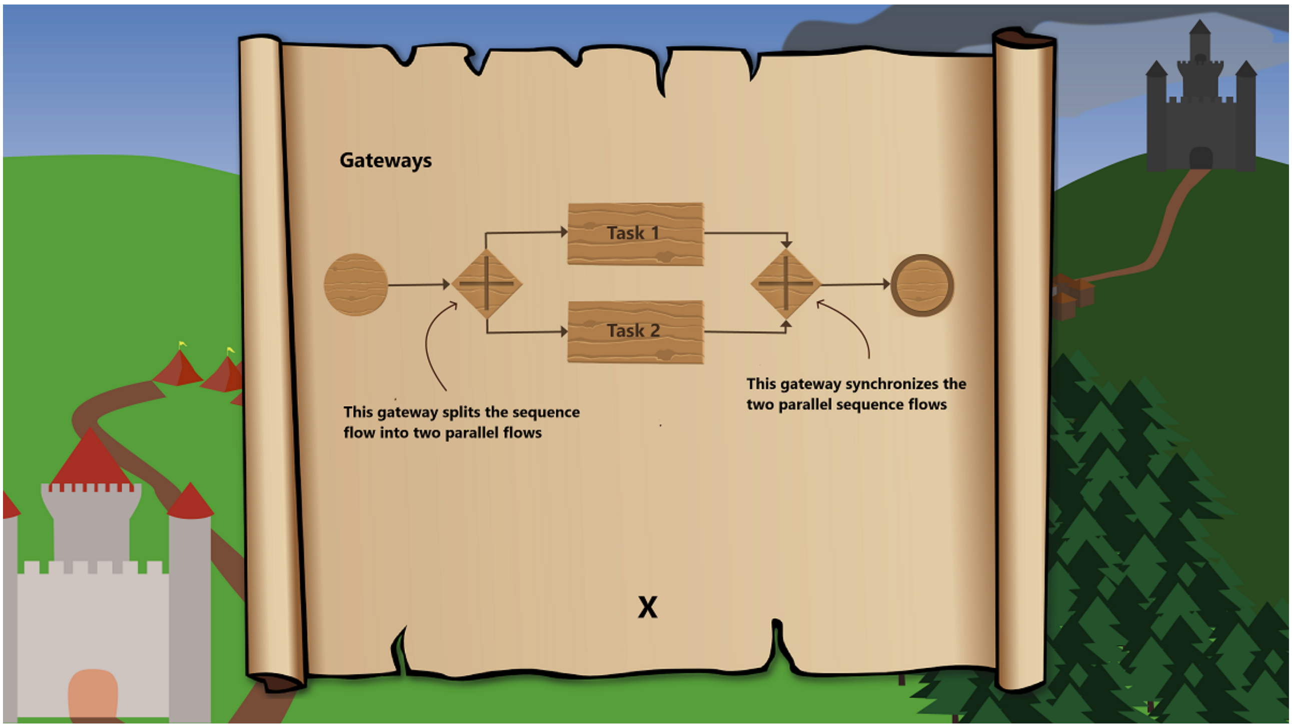
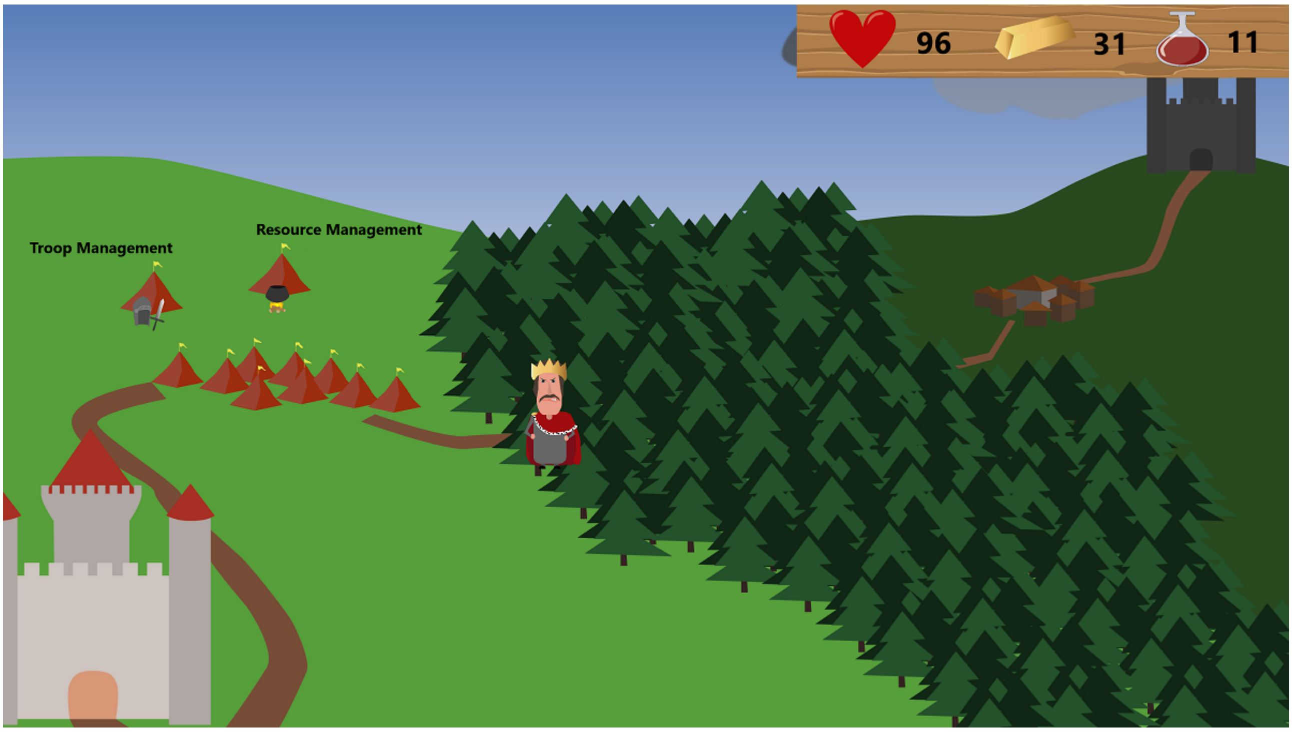


Figure 4. Troop and resource management.



Comprehension Questions

For the evaluation of the impact of the serious game (ie, immediate [study 1] and follow-up [study 2]), all participants in both studies had to answer ten true or false comprehension questions on five different process models in a separate questionnaire. Specifically, two comprehension questions were asked per process model, which were expressed in terms of BPMN version 2.0. The five process models represented five different levels of complexity (ie, beginner, basic, intermediate, advanced, and expert).

The beginner process model was only composed of basic modeling elements. With the rising level of complexity, new BPMN version 2.0 elements were added, and the total number of elements was increased. The guidelines from studies by Becker et al and Mendling et al [31,32] as well as an adopted cognitive complexity measure proposed in a study by Gruhn and Laue [33], were used in the creation of the process models to allow categorization into these five levels of complexity. The process models documented no concrete scenario, and single alphabetic letters were used to label the process model elements (ie, abstract labeling type). The ten comprehension questions referred to the syntactic and semantic dimension of the process models and were used to evaluate the impact (ie, immediate and follow-up) of the serious game. The comprehension questions were defined by two process modeling experts in a consensus-building process.

In study 1, both groups received the same questionnaire with the same ten comprehension questions. In study 2, to ensure comparability between both studies, a similar but still different set of process models and related comprehension questions were used. More specifically, a small change was made in the structure of the process models and respective element labeling. For the comprehension questions, different questions were used, but they referred further to the syntactic and semantic dimensions of the process models.

Participants

In study 1, the sample size comprised 81 students from an entry course in Business Process Management at Ulm University. Until the beginning of study 1, the entry course introduced the fundamentals of business process modeling to the students.

Overall, 36 participants were female and the average age was 23.67 years (SD 3.19). Based on a demographic questionnaire, 47 participants stated they had little to no experience in process modeling and comprehension as well as in working with BPMN version 2.0 (ie, 0), while 20 participants had average experience (ie, 1), and 14 participants had a high level of experience (ie, 2). The participants were divided into two groups (ie, control group and game group) using the round-robin approach (ie, alternating assignment into one of the two groups). Moreover, the round-robin approach ensured that both groups had similar characteristics in terms of baseline variables. Due to restrictions on the availability of mobile devices, 3 participants who belonged to the game group had to be assigned to the control group instead. In total, the control group consisted of 44 participants and the game group consisted of 37 participants. The baseline comparisons between the control and the game group participants are presented in Table 1. *P* values presented were calculated using the Fisher exact test.

In study 2, 64 students were enrolled from the same Business Process Management entry course at Ulm University. During the period between study 1 and study 2, the entry course taught the process modeling aspects that are included in the serious game.. For this reason, a general increase in the comprehension question scores was expected in study 2. All participants were divided into a follow-up control group and a follow-up game group. Specifically, 30 participants who played the serious game in study 1 (ie, identified by a generated pseudocode) were allocated to the follow-up game group [ie, FU_Game]. However, seven game group participants from study 1 did not participate in study 2 because of term fluctuation. A total of 34 participants who either participated in study 1 and did not play the game (n=31) and new participants who were not part of study 1 (n=3) were allocated to the follow-up control group [ie, FU_Control]. A total of 13 control group participants from study 1 did not participate in study 2 again because of term fluctuation. Overall, 27 females participated in study 2, and the average age was 23.50 years (SD 3.18). From the demographic questionnaire, 37 participants with little to no experience, 19 participants with average experience, and 8 participants with high experience in process modeling and comprehension took part in the study. The control and game group participants were compared along baseline variables, and the results are presented in Table 2. *P* values presented were calculated using the Fisher exact test.

Table 1. Sample description and comparison of study 1 in baseline variables.

Variables	Control (n=44)	Game (n=37)	*P* value
Sex, n (%)			.65
Female	21 (52)	15 (41)	
Male	23 (48)	22 (59)	
Average age (years), mean (SD)	23.23 (3.09)	24.20 (3.25)	
Age, n (%)			.24
Aged <25 years	32 (73)	22 (59)	
Aged >24 years	12 (27)	15 (41)	
Experience, n (%)			>.99
0 (none to little)	26 (59)	21 (57)	
1 (average)	11 (25)	9 (24)	
2 (high)	7 (16)	7 (19)	

Table 2. Sample description and comparison of study 2 in baseline variables.

Variables	FU_Control (n=34)	FU_Game (n=30)	*P* value
Sex, n (%)			.45
Female	16 (47)	11 (37)	
Male	18 (53)	19 (63)	
Average age (years), mean (SD)	23.15 (3.09)	23.90 (3.24)	
Age, n (%)			.43
Aged <25 years	25 (73)	19 (63)	
Aged >24 years	9 (27)	11 (37)	
Experience, n (%)			>.99
0 (none to little)	20 (59)	17 (57)	
1 (average)	10 (29)	9 (30)	
2 (high)	4 (12)	4 (13)	

Comprehension Questions Score

To investigate the immediate and follow-up impact of the serious game, participants were asked to answer ten true or false comprehension questions on five different process models (ie, two questions each). The process models were categorized into five different levels of complexity, and five questions had to be answered per process model. The sum of the correct answers was used as the respective performance measure in study 1 and study 2.

Study Design

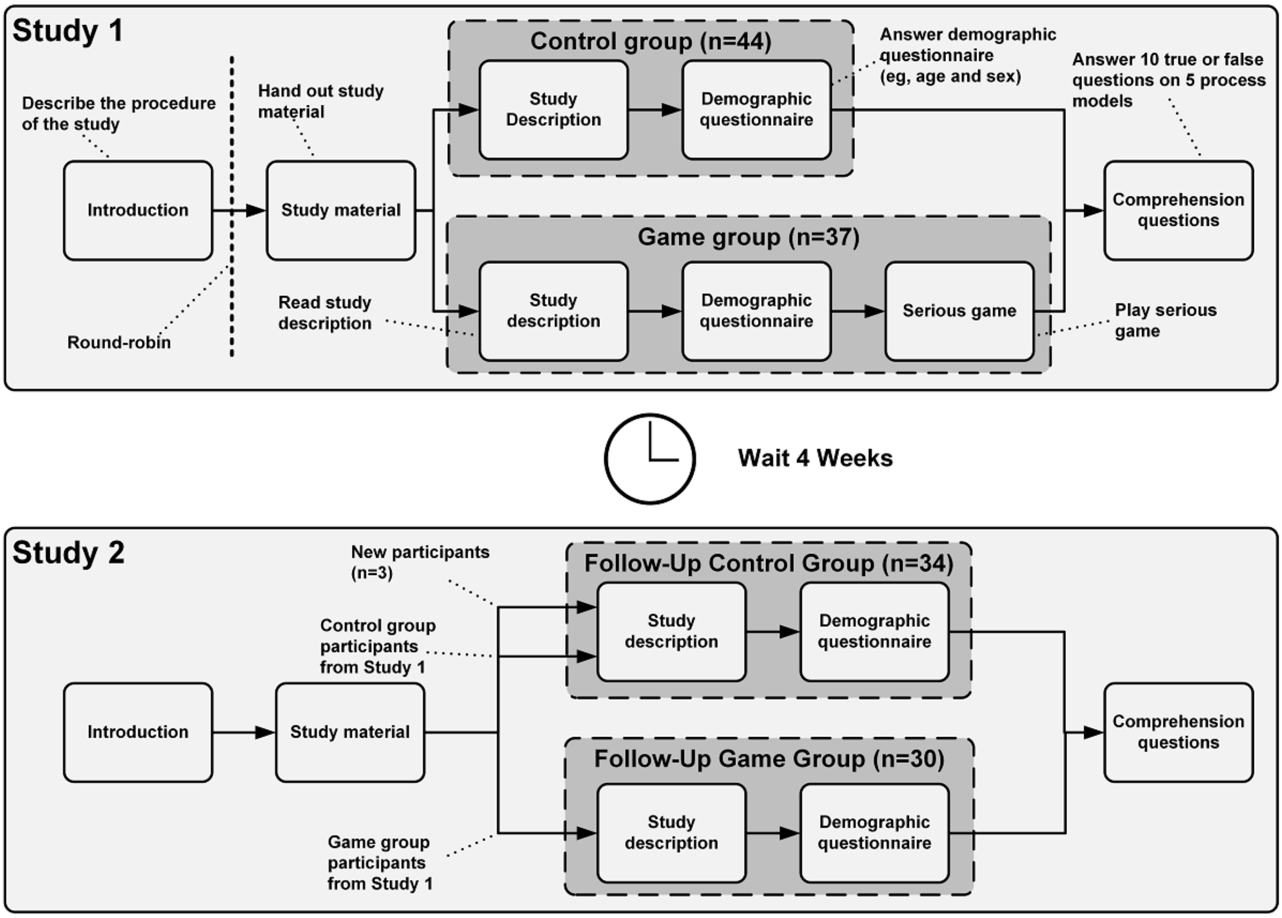
The design of the study is based on the guidelines set out by Wohlin et al [34]. Before conducting the two studies, a pilot study of the serious game was performed that involved three participants who did a playtest with a think-aloud protocol. All three participants had experience with process modeling and comprehension as well as with BPMN version 2.0. The playtest ensured that no severe bugs or design flaws were in the final game. Think-aloud protocols support the identification of misunderstandings and usability problems that can be addressed accordingly. Following this, several quality improvements were implemented in the game's final version, which included, among others, the improvement of the use of the single BPMN version 2.0 elements and the process models that needed to be modeled. Also, apart from the perceived fun factor, the educational emphasis of introducing BPMN version 2.0 and corresponding elements was discernible. Furthermore, for the evaluation of the immediate and follow-up impact of the serious game on process model comprehension, a longitudinal study design with two measurement time points was chosen. The time between the two measurements was four weeks.

The procedure of study 1 (ie, focus on the immediate impact of the serious game) was as follows: the study participants were welcomed, and the overall study procedure was explained. Following this, the participants were divided according to the round-robin approach (ie, alternating assignment into one of the two groups) into a control group and game group. After this step, study materials (ie, study description, demographic questionnaire, and study trial) were handed out to the participants. In the control group, first, the study description had to be read. Then, the participants needed to answer the demographic questionnaire to capture relevant demographic data (eg, age and gender).

After the demographic questionnaire was answered, participants had to answer ten true or false comprehension questions on five differently complex (ie, beginner, basic, intermediate, advanced, and expert) process models (ie, two comprehension questions per process model). The comprehension questions solely referred to the syntactical rules or the semantic description of the process models. After completing this step, the study ended. Thus, the control group did not play the serious game and only answered the comprehension questions. The game group, in turn, played the serious game on mobile devices after answering the demographic questionnaire to evaluate the immediate impact thereof. The serious game was played only once, with a playthrough taking about 20 minutes to complete. After playing the serious game, ten true or false comprehension questions (ie, the same as in the control group) on five differently complex process models had to be answered.

In study 2 (ie, focus on the follow-up impact of the serious game), four weeks after study 1, participants were identified by a generated pseudocode based on if they had played the serious game in study 1 or not. Those who played the serious game in study 1 made up the follow-up game group, and those who did not play the game (either control group participants in study 1 or new participants) were the follow-up control group. The serious game was not played again in study 2. Afterward, all participants had to answer ten true or false comprehension questions on five process models of varying complexity. The comprehension questions and respective process models were like the ones used in study 1 to ensure comparability between the studies. The entire study design for study 1 and study 2 is outlined in Figure 5. During the four weeks between the two measurements (ie, study 1 and study 2), the entry course on Business Process Management introduced the aspects of BPMN version 2.0 used in the game to the participants as part of the syllabus. For this reason, we expected an increase in the comprehension question score in study 2 compared to study 1 for both groups.

Figure 5. Study design.



Results

Descriptive Statistics

Regarding study 1, Table 3 presents descriptive results obtained from the control group and game group immediate after study 1. It shows the average correct answers per complexity level as well as the sum thereof. As can be seen from Table 3, participants who played the serious game (ie, game group) achieved a better result in the comprehension questions compared with participants who did not play the serious game (ie, control group). In general, the control group achieved a mean of 5.70 (SD 1.46), whereas the game group achieved a mean of 6.86 (SD 1.55). Furthermore, a decrease in the score is noticeable in both groups with rising level of process model complexity.

Regarding study 2, Table 4 shows descriptive results from both groups (ie, follow-up control group and follow-up game group). Once again, the table shows the average correct answers per complexity level and the sum thereof for the ten true or false questions that were asked. In general, there is an increase in the comprehension question score between study 1 and study 2. This general increase is explained by the fact that participants spent considerable time working with process models as well as BPMN version 2.0 in the context of the entry course. However, comparing the results from the follow-up control group and follow-up game group, the same observation as seen in study 1 is discernible. Specifically, after four weeks, participants who were in the game group in study 1 achieved a better result at answering comprehension questions compared to participants who did not play the serious game. The participants of the follow-up control group achieved a mean comprehension score of 6.65 (SD 1.63), while the follow-up game group achieved a mean score of 7.90 (SD 1.37).

Table 3. Descriptive results from study 1.

Group	Level of complexity (score), mean (SD)					
	Beginner	Basic	Intermediate	Advanced	Expert	Sum
Game (n=37)	1.68 (0.53)	1.59 (0.55)	1.41 (0.64)	1.16 (0.65)	1.03 (0.76)	6.86 (1.55)
Control (n=44)	1.55 (0.59)	1.23 (0.71)	1.23 (0.68)	0.95 (.53)	0.75 (.61)	5.70 (1.46)

Table 4. Descriptive results from study 2.

Group (n)	Level of complexity (score), mean (SD)					
	Beginner	Basic	Intermediate	Advanced	Expert	Sum
FU_Game (n=30)	1.87 (0.35)	1.73 (0.52)	1.57 (0.50)	1.57 (0.50)	1.17 (0.70)	7.90 (1.37)
FU_Control (n=34)	1.61 (0.49)	1.44 (0.70)	1.38 (0.60)	1.24 (0.74)	0.97 (0.67)	6.65 (1.63)

Inferential Statistics

To evaluate the reported descriptive results for statistical significance, analyses of variance for repeated measurements were performed with the performance measure score as dependent variable (Greenhouse-Geisser correction was applied). For these analyses, the within-subject factor had five levels and was the level of process model complexity, and the between-subject factor had two levels and consisted, for all research questions, of the sample comparison of interest (ie, control vs game and follow-up control vs follow-up game). The main effects of the level of complexity and sample comparison, as well as the interaction effect (ie, complexity×sample comparison), were evaluated. In addition, in the event of significance for the level of complexity and the interaction effect, repeated contrasts were employed. Finally, for question 1 and questions 2, Hedges g was calculated to quantify the effect of the serious game. Effect sizes will be interpreted as follows: 0.20=small effect, 0.50=medium effect, and 0.80=large effect. All two-tailed statistical tests were performed, and the significance value was set to *P*<.05.

Results for Research Question 1

Table 5 presents the results for the performance measure score for research question 1.

Main effect 1, the level of complexity, was significant (*P*<.001), and repeated contrasts showed that complexity 2 (*P*=.04) had a lower score (mean 1.40; SD 0.66) than complexity 1 (mean 1.60; SD 0.56) and, in addition, complexity 3 (*P*=.36) did not have a lower score (mean 1.31; SD 0.66) than complexity 2. However, complexity 4 (*P*=.02) had a lower score (mean 1.05; SD 0.59) than complexity 3, whereas complexity 5 (*P*=.08) did not have a lower score (mean 0.88; SD 0.70) than complexity 4. Furthermore, main effect 2, the sample comparison, reached statistical significance (*P*<.001), and the control group had significantly lower scores than the game group. The interaction effect did not reach significance. Finally, a Hedges g was determined for each level of complexity and the sum thereof as between-group effect size. Hedges g for beginner, basic, intermediate, advanced, and expert was 0.23, 0.56, 0.27, 0.35, and 0.41, respectively, and Hedges g for sum was 0.77.

Table 5. Inferential statistics for research question 1.

Effect	Performance measure score	
	F test (df)	*P* value
Main effect of the level of complexity	17.19 (3.68, 290.50)	<.001
Main effect of sample comparison	12.05 (1, 79)	<.001
Interaction effect	0.45 (3.68, 290.50)	.76

Results for Research Question 2

Table 6 shows the results for the performance measure score with respect to research question 2.

Main effect 1, the level of complexity, was significant (*P*<.001), and repeated contrasts showed that complexity 2 (*P*=.11) did not have a lower score (mean 1.58; SD 0.64) than complexity 1 (mean 1.74; SD 0.45) and, in addition, complexity 3 (*P*=.26) did not have a lower score (mean 1.47; SD 0.56) than complexity 2. Furthermore, complexity 4 (*P*=.50) did not have a lower score (mean 1.39; SD 0.66) than complexity 3, whereas complexity 5 (*P*=.002) had a lower score (mean 1.06; SD 0.69) than complexity 4. Moreover, main effect 2, the sample comparison, reached statistical significance (*P*=.01), and the follow-up control group had significantly lower scores than the follow-up game group. Furthermore, the interaction effect did not attain significance. Finally, a Hedges g was determined for each level of complexity and the sum thereof as a between-group effect size. Hedges g for beginner, basic, intermediate, advanced, and expert was 0.60, 0.46, 0.34, 0.51, and 0.29, respectively, and Hedges g for sum was 0.82.

Table 6. Inferential statistics for research question 2.

Effect	Performance measure score	
	F test (df)	*P* value
Main effect of the level of complexity	12.28 (3.81, 236.45)	<.001
Main effect of sample comparison	10.89 (1, 62)	.01
Interaction effect	0.19 (3.81, 236.45)	.94

Discussion

Principal Findings

This study evaluated a serious game to foster business model comprehension. First, we evaluated whether participants who played the serious game showed a better immediate performance than participants who did not play the serious game, and also whether this depended on the level of complexity of the process models (ie, research question 1). We found that participants who played the serious game had a significantly better immediate performance measure than participants who did not play the serious game and that this difference between the game group and control group was not affected by process model complexity. The corresponding between-group effect size was medium to large for the sum score of model comprehension (g=0.77). Based on the presented results, it can be concluded that the serious game had a significant, positive, immediate, impact on process model comprehension. Moreover, in this scenario, the comprehension of process models is not improved through direct approaches focusing on respective comprehensibility. In turn, with an indirect approach about how to model processes, an improvement in process model comprehension was addressed.

Second, we analyzed whether participants who played the serious game showed a better follow-up performance measure than participants who did not play the serious game. It was again analyzed whether this depended on the level of complexity of the process models. We found that participants who played the serious game had a significantly better follow-up performance measure than participants who did not play the serious game and that this group difference was not affected by the process model complexity. Furthermore, Hedges g implied a large effect for the sum score of model comprehension (g=0.82). Thus, the serious game had a significant positive impact on process model comprehension at follow-up.

Finally, for both research questions, main effect 1 reached significance all the time, indicating that process models are more difficult to comprehend when they are more complex.

Limitations

First, the external validity and generalizability are limited because only students were examined. Second, to investigate the impact of the serious game on process model comprehension, participants needed to answer ten true or false comprehension questions on five different process models. To ensure comparability of the comprehension questions between studies 1 and 2, different but still similar process models were used (ie, similar process model structure but different element labeling style). Thus, participants in study 2 might have noticed similarities in the process models while answering the comprehension questions and, consequently, answering of respective questions could have been easier. Third, the potential fun factor while playing the serious game may have affected the motivation of participants in answering the comprehension questions. If a task that is associated with some fun factor is completed, then the attitude for the following task is likely to be different and potentially more positive. Accordingly, the motivation of participants of study 1 in the game group could have been different from the control group, resulting in a better comprehension questions score. Fourth, there were participants (n=3) who participated in study 2 but not in study 1. These participants were considered to be a part of the control group instead. Fifth, the better comprehension question scores of the follow-up game group could also be explained by the fact that those participants spent more time working with process models and BPMN in the period between the two measurements (ie, four weeks between study 1 and study 2) during the entry course. Finally, the number of participants in study 1 and study 2 was not the same because there is a typical decrease in the number of students in a course during the term.

Implications

The provided insights have several implications for practice and research. Particularly noteworthy is the positive immediate and follow-up impact of the serious game in the context of process model comprehension. As known from other domains, this positive effect from serious games may be used to improve formal training in process model comprehension for practitioners or domain experts [35]. Furthermore, existing tools in this context may be enriched with features or aspects of the serious game to improve respective model comprehension.

Moreover, a tool can be developed using the aspects of the serious game to increase general motivation [36]. Practitioners or domain experts can also be supported in their comprehension as well as the creation of process models. Moreover, research on process model comprehension can better investigate the precise impact of specific aspects from a serious game, particularly, which aspects of these game (eg, high score and item crafting) have a beneficial impact and which aspects have an opposite effect [37]. With the use of serious games, another approach can be used to investigate learning success as well as engagement in process model comprehension. Compared to serious games, other game-based principles (eg, gamification and playful interaction) and their impact on process model comprehension can be considered in future research [38]. Finally, research questions may address the impact of a serious game on, for example, cognitive load [39], or if a serious game supports the reduction of the perceived cognitive load while comprehending process models.

Future Work

In general, based on the insights of study 1 and study 2, the application of the developed serious game had a positive, immediate, and follow-up impact on process model comprehension. Although results look auspicious, additional studies are needed to replicate these findings. The participants of the current study were students taking part in a Business Process Management entry course at a university and studies with other samples are needed to enhance generalization of the results (external validity). For example, it is interesting to investigate the impact of the serious game while including domain experts from different fields (eg, doctors) to investigate whether domain experts are able to learn how to comprehend process models while playing the serious game. Such studies including samples that are not familiar with process modeling should include an assessment of process model comprehension performance at baseline, i. e. before the game group plays the serious game in order to evaluate pre-post changes in the game group vs. control group. The current study included only post- and follow-up assessments, since participants were familiar with business process modeling at least to some extent at the start of the study. To enhance internal validity, a randomized controlled study would be welcome, since the current studies are based on a quasi-experimental design.

The game will also be continuously enriched with new features. These include the introduction of additional BPMN version 2.0 process modeling elements, which has been considered to enable the comprehension of complex or even real-world process models. The focus of the paper at hand was on process model comprehension, and thus we will investigate the impact of the serious game in the context of process modeling as well. Therefore, a feature is currently being implemented that records the steps of process modeling for participants. The recording feature, in turn, will allow us to examine the single steps of process modeling in more detail to enhance our general understanding of working with these models. Finally, support for other process modeling languages (eg, event-driven process chains and Unified Modeling Language activity diagram [40]) will be the subject of future developments.

Summary

This paper presented the serious game, Tales of a Knightly Process, which introduces the basics of process modeling to foster the comprehension of these models. We also evaluated the immediate and follow-up impact of the serious game on process model comprehension. The results obtained from both studies showed that the serious game had a significant, positive, immediate and follow-up impact on the comprehension of process models. Furthermore, it was observed that process models are increasingly difficult to comprehend with a rising level of model complexity. Altogether, the obtained results highlight the positive impact of the serious game in the field of process model comprehension. With this work, we can therefore confirm and recommend the use of game designs as well as related principles (ie, serious games and gamification) in a nongame context (ie, process model comprehension).

Authors' Contributions

MW substantially contributed to Tales of a Knightly Process, study design, data acquisition, data analysis, and data interpretation, and drafted and revised the paper. RP substantially contributed to Tales of a Knightly Process and data interpretation and revised the paper. TP substantially contributed to data analysis and data interpretation and revised the paper. MR substantially contributed to Tales of a Knightly Process and revised the paper.

Conflicts of Interest

None declared.

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Abbreviations

BPMN: Business Process Model and Notation

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Original Paper

The Adoption of a Virtual Reality–Assisted Training System for Mental Rotation: A Partial Least Squares Structural Equation Modeling Approach

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Abstract

Background: Virtual reality (VR) technologies have been developed to assist education and training. Although recent research suggested that the application of VR led to effective learning and training outcomes, investigations concerning the acceptance of these VR systems are needed to better urge learners and trainees to be active adopters.

Objective: This study aimed to create a theoretical model to examine how determining factors from relevant theories of technology acceptance can be used to explain the acceptance of a novel VR-assisted mental rotation (MR) training system created by our research team to better understand how to encourage learners to use VR technology to enhance their spatial ability.

Methods: Stereo and interactive MR tasks based on Shepard and Metzler's pencil and paper test for MR ability were created. The participants completed a set of MR tasks using 3D glasses and stereoscopic display and a 6-degree-of-freedom joystick controller. Following task completion, psychometric constructs from theories and previous studies (ie, perceived ease of use, perceived enjoyment, attitude, satisfaction, and behavioral intention to use the system) were used to measure relevant factors influencing behavior intentions.

Results: The statistical technique of partial least squares structural equation modeling was applied to analyze the data. The model explained 47.7% of the novel, VR-assisted MR training system's adoption intention, which suggests that the model has moderate explanatory power. Direct and indirect effects were also interpreted.

Conclusions: The findings of this study have both theoretical and practical importance not only for MR training but also for other VR-assisted education. The results can extend current theories from the context of information systems to educational and training technology, specifically for the use of VR-assisted systems and devices. The empirical evidence has practical implications for educators, technology developers, and policy makers regarding MR training.

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KEYWORDS

virtual reality; computer simulation; educational technology; training programs

Introduction

Background

Research on the acceptance of new information systems and technologies provides empirical evidence guiding decision-making processes in regard to system developments, educational implications, and other practices. For example, in the fields of information systems and behavioral science, robust models (eg, technology acceptance model, TAM; [1]) have been proposed and repeatedly replicated in different contexts to examine and better understand the processes of accepting new technologies and systems. In recent years, virtual simulation tools such as the VIVE (HTC Corporation) have been developed and have become more prevalent. These tools create a user experience that better engages cognitive, visual, and motional perceptions. As virtual reality (VR) is different from other information systems—in that users can perceive stereoscopic 3D objects and it is capable of changing fields-of-view while simultaneously interacting with the content via virtual controllers or motion sensors—this study sees a need to explore users' acceptance of such emergent technology.

Although VR technologies are relatively new and require acceptance research, they have been applied to modern learning and training systems and shown effective outcomes (eg, [2,3]). For instance, a recent study conducted by Yeh et al [2] explored using VR for mental rotation (MR) training. MR is a kind of cognitive ability that uses human spatial imagination to rotate an object in a 2D or 3D space [2,4,5]. In a stereoscopic and interactive virtual environment, the results of pretest-posttest comparison suggested that the VR training improved learners' MR ability [2]. These results led to this study's interest in gauging the factors that would encourage learners to use the VR system to enhance their spatial ability, as the MR ability influences an individual's learning activities relying on spatial cognitions including those in the field of medical science. Take anatomy learning as an example. Research has shown that MR ability and the outcome of anatomy learning were positively correlated [6,7]. Hoyek et al [7] conducted an experiment comparing 3 groups of anatomy learning: (1) attending anatomy class and receiving MR training (ie, the treatment group), (2) attending anatomy class only (ie, the comparison group), and (3) neither attending anatomy class nor receiving MR training (ie, the control group). The results concluded that the intervention of MR training positively influenced the students' performance in the anatomy test.

Given the developments and research stated above, this study intended to understand the users' complex psychological processes of accepting the VR-assisted MR training system. The empirical results could extend current theories of acceptance from the context of information systems to educational and training technology, specifically for VR-assisted systems and devices. The main goals of this study were, therefore, to (1) create a behavioral model to better understand the adoption of VR technology for MR training, (2) provide suggestions to educators and technology designers regarding the application and improvement of VR training technology for MR, and (3) establish a stepping stone for future researchers and practitioners interested in incorporating VR technology into other educational and training activities for their users.

Theoretical Framework and Research Hypotheses and Question

To comprehend how an information system is accepted by users, Davis et al [1] proposed the TAM, developed from Fishbein and Ajzen's [8] Theory of Reasoned Action for predicting and understanding an individual's rational behavior and decision making. The TAM model has been frequently used to research the acceptance of a new information and computer system and technology, including those for educational purposes and settings (eg, [9,10]) and has recently been applied to better understand the adoption of VR-assisted training and educational systems (eg, [11,12]). Regarding the design of user interface, TAM assumes that perceived ease of use (PEOU) influences users' attitude (ATT) toward an information system and that ATT affects their behavioral intention to use (BIU) it. This study hypothesized that the same effects apply to our VR-assisted MR training system.

> *H1: Users' PEOU of the MR system predicts their positive ATT toward it.*
>
> *H2: Users' positive ATT toward the system predicts their BIU.*

As technology has developed, the TAM model has progressed and evolved. Davis et al [13] found that both extrinsic (eg, perceived usefulness [PU] and PEOU) and intrinsic (eg, cognitive enjoyment) motivations affected users' behavioral intention and actual use of an information system. Extrinsic motivations are involved with the rewards via actual use, such as the enhancement of job efficiency and increase of salary. On the other hand, intrinsic motivations emphasize the rewards in the experience as the ultimate goal, such as the enjoyment of an activity. By empirically testing the relationships of intrinsic and extrinsic motivations, Davies found that PU and perceived enjoyment (PE) were affected by PEOU. Hence, we postulated H3 for the use of our system.

> *H3: Users' PEOU affects their PE when using the MR training system.*

Except for the PU and PEOU as the 2 determinants, researchers started to explore an individual's enjoyable experiences after Davis et al [13]. PE has been verified to have effects on ATT and satisfaction (SAT) with information systems and technology. For example, PE influenced users' positive ATT and intention to use the World Wide Web [14]. In digital learning, trainees' cognitive playfulness affected their learning outcomes, positive mood, and SAT with the training system [15]. On the basis of this evidence, we proposed H4 and H5.

> *H4: Users' PE predicts their positive ATT toward the MR training system.*
>
> *H5: Users' PE predicts their SAT with the MR training system.*

Previous studies suggested that users' SAT is a predictive factor for the adoption of new information technology. According to expectation-confirmation model (ECM; [16]), users' perception of usefulness and confirmation (ie, whether the experience of information technologies meets their expectation) influences their SAT with the system, and the level of SAT predicts their continued intention to use the system. Ho's [17] study on electronic learning platforms found that users' SAT with the technology also affected their ATT toward the system. Given these findings from previous relevant studies, we hypothesized that trainees' SAT with the VR-assisted MR training system would influence both their ATT toward and intention to use the system.

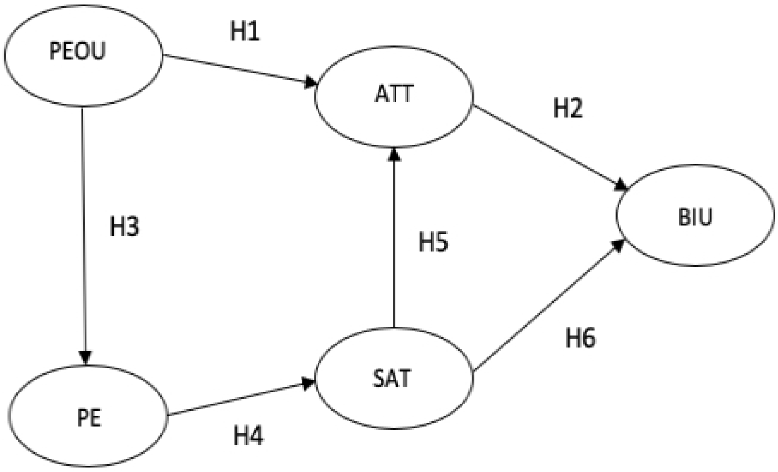
> *H6: Users' SAT with the system predicts their positive ATT.*
>
> *H7: Users' SAT with the system predicts their BIU.*

Figure 1 shows all the proposed hypotheses and the research model for this study.

To better understand how each factor interacts with others to affect learners' intention to use the VR-assisted MR training system and to provide more detailed implications for future researchers and practitioners, we asked the following research question to gauge the indirect effects among the constructs in this study.

> *RQ: Are there any indirect effects among the constructs in the proposed model?*

Figure 1. The proposed theoretical research model includes perceived ease-of-use (PEOU), perceived enjoyment (PE), attitude (ATT), satisfaction (SAT), and behavioral intention to use the system (BIU). H: hypothesis.



Methods

System Design

Shepard and Metzler [18] developed a paper-based MR test. Two 3D objects having the same geometric form but in different orientations were created on a 2D sheet. Trainees were typically asked to identify whether these 2 objects are the same. Developed from Shepard and Metzler's MR tasks, this study adopted 12 stereo and interactive MR tasks (2 for the purpose of practice and 10 for formal training) for our VR-assisted interactive MR training system. OpenGL (Khronos Group) [19], a computer graphic software, was used to create the 3D objects (see Figure 2 for the visual demonstration), and Quad-Buffer Stereo [20] was used in OpenGL to create 120 frames per second for stereovision. For the hardware, RealID shutter glasses (ie, 3D glasses) were used by the participants (Figure 3). The mechanism of stereovision relies on visual persistence and the cross-display of 120 images between 2 eyes. For the interactive experience, Unity engine [21] was applied, so users could virtually rotate the MR subjects via a 6-degree-of-freedom (dof) controller (ie, joystick; Figure 4). In our study, trainees were asked to observe and rotate an MR object and drag it to superimpose a replicate on the other side of the screen that has the same geometric form but a different orientation. Once the 2 MR objects perfectly matched, the specific single MR task was accomplished.

Figure 2. The stereoscopic interactive mental rotation tasks created by the research team.

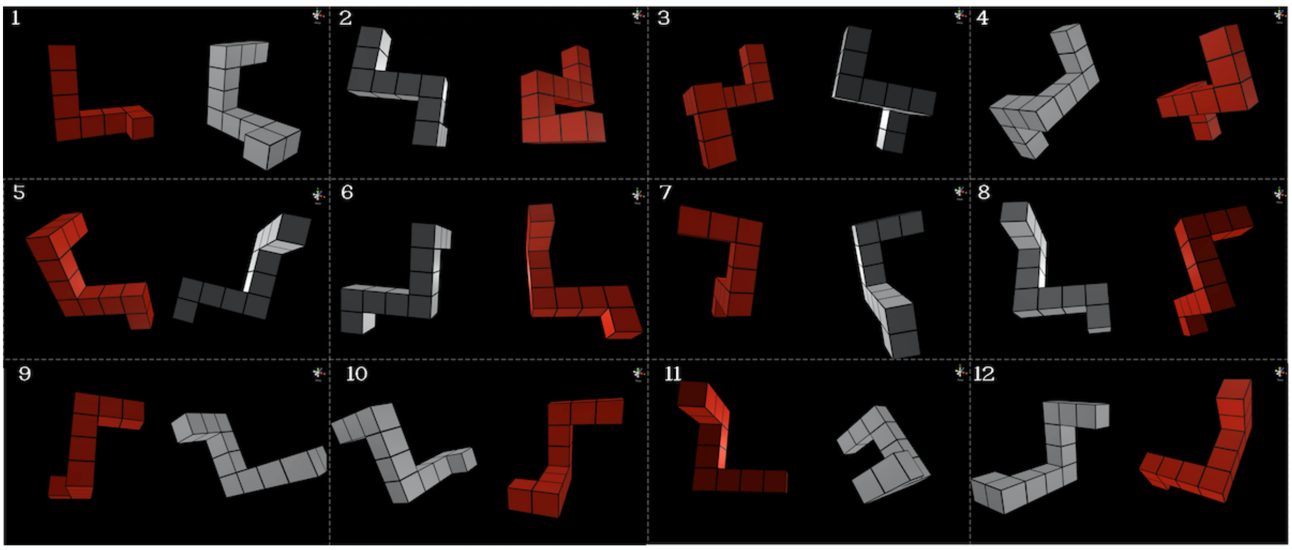
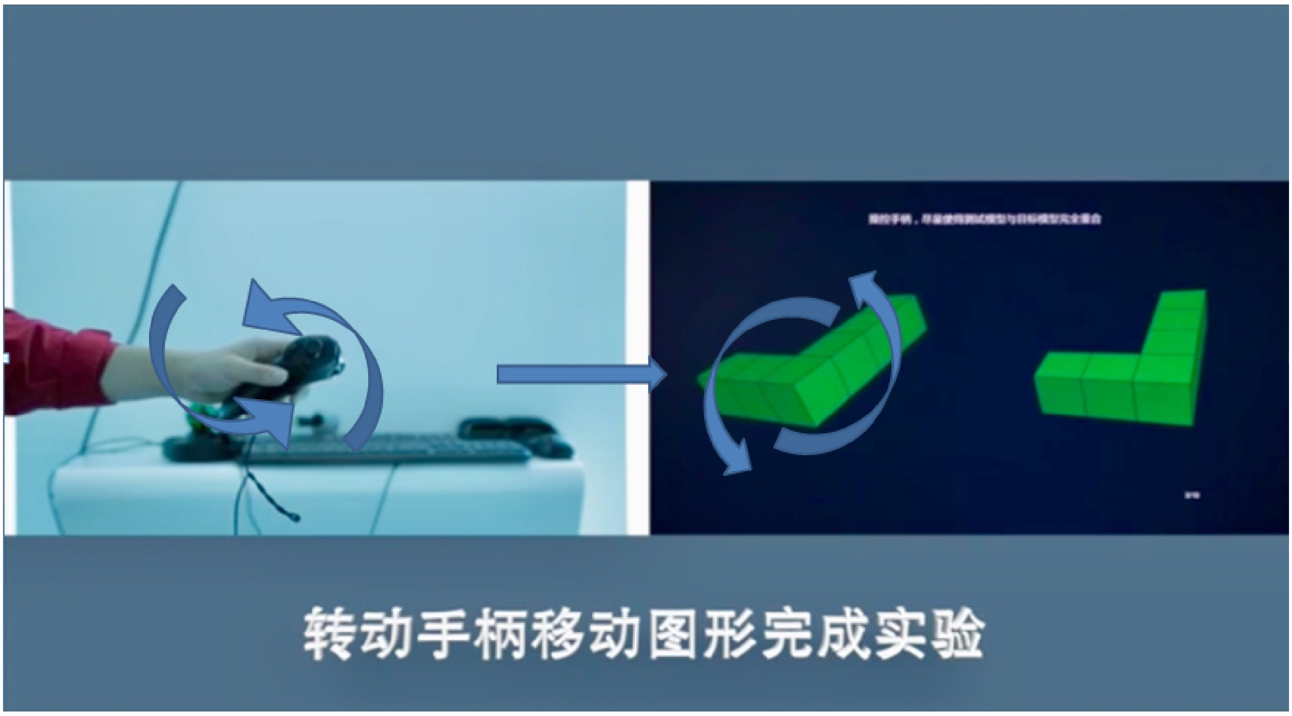


Figure 3. 3D glasses were used to facilitate the interactive virtual reality experience for mental rotation tasks (written, informed consent was obtained from the individual for publication of the image).

Figure 4. Joystick controller was used to facilitate the interactive virtual reality experience for mental rotation tasks.



Participants and Procedure

This study used partial least squares structural equation modeling (PLS-SEM) for data analysis. PLS-SEM is one of the most used analytical technique by management information system and marketing researchers, and studies applying PLS-SEM have been published in journals such as *MIS Quarterly* [22]. PLS-SEM suggests a 10-time rule for the sample size. The sample size must be 10 times greater than (1) the maximum number of paths a latent variable has and (2) the greatest indicators (items) a latent variable has in the model [23]. This study used a data subset of 55 participants from an earlier developed experimental study [24], which surpassed the

2 threshold requirements. The students in this study were all recruited from the same large research university in Shanghai, China, in early 2018. Each of them received 10 RMB (about US $1.5) to compensate their time. Their ages ranged from 18 to 26 years (mean 20.29, SD 1.85; median 20.00), with a control of approximate numbers of male (n=29) and female (n=26) participants. They came from diverse majors, including journalism, social science, psychology, Chinese, German, museum studies, mathematics, science, physics, microelectronics, electrical engineering, medicine, medical, chemistry, and electronical information science and technology. For the conditions analyzed in this study, the participants were first asked to watch an instruction video to understand the basic concept of MR and how to use the VR-assisted training equipment. Afterward, they were asked to use the VR equipment (ie, the stereoscopic display and 3D glasses and joystick controller) to perform 2 MR tasks for practice and 10 MR tasks for formal training, which were created by our research team, followed by a Web-based questionnaire. Owing to the nature of a data subset from a previous experimental study applying a reverse group design, nearly half of the participants in this study had experienced another condition—using a 3-dof computer mouse as the controller before their repeated practice using a 6-dof joystick controller. To prevent potential order effects, we added control variables reflecting the influences caused by the differences between the 2 groups to our analyzed PLS-SEM model. None of the control variable's effect was statistically significant, which indicated a similarity between groups.

Measurement

The measurement for the individual constructs were developed from previous theories and research in information systems and technology, some of which were introduced in the literature review (Table 1). Seven-point Likert scales were applied to PEOU, ATT, PE, and BIU. Semantic measures (7-point scales) were used for the constructs of SAT.

Table 1. Measurement scales.

Construct	Item	Cronbach alpha
Perceived ease of use [25]	1. My interaction with this MR[a] system was clear and understandable. 2. Interacting with this MR system did not require a lot of my effort. 3. I found this MR system difficult to use (reversed; withdrawn because of a low factor loading). 4. I found it easy to get this MR system to do what I wanted it to do.	.769
Attitude [26]	1. Using this MR system is a good idea. 2. Using this MR system is a wise idea. 3. I dislike the idea of using this MR system (reversed; withdrawn because of a low factor loading). 4. Using this MR system is pleasant.	.935
Perceived enjoyment [13]	1. I found using this MR system to be enjoyable. 2. The actual process of using this MR system was pleasant. 3. I had fun using this MR system.	.959
Satisfaction [16]	How did you feel about your overall experience of this MR system? (sematic measures): (1) Very dissatisfied <– –> Very satisfied, (2) Very displeased<– –>Very pleased, (3) Very frustrated<– –>Very contented, and (4) Absolutely terrible<– –>Absolutely delighted	.862
Behavioral intention of use [25]	1. Assuming I had access to this MR system, I intend to use it. 2. Given that I had access to this MR system, I predict that I would use it.	.948

[a]MR: mental rotation.

Results

This study used IBM SPSS and SmartPLS 3 to analyze data. In SmartPLS 3, the *outer model* represents the *measurement model*, whereas the *inner model* is the same as the "structural model" in other structural equation modeling (SEM) software. Before the SEM analysis, the data were examined for outliers and univariate normality distributions. One case was deleted because of its extreme z-score for a measured item. Afterward, the researchers examined the validity and reliability for the outer model in SmartPLS 3. As can be seen in the measurement, all the latent variables were considered internally consistent according to Nunnally and Bernstein's [27] rule of 0.7 for the Cronbach alpha, as they ranged from 0.769 to 0.959. The convergent validity was met based on 3 criteria: (1) The indicators for individual constructs surpassed the threshold value of 0.7, (2) the composite reliability values were greater than 0.6, and (3) each construct had a coefficient of average variance extracted (AVE) no less than 0.6 ([28,29]; see Table 2 for more details on the convergent validity).

Table 2. Convergent validity.

Construct	Item	Standardized loading	Composite reliability	AVE[a]	√AVE
PEOU[b]	PEOU1	0.837	—[c]	—	—
	PEOU2	0.871	—	—	—
	PEOU4	0.772	0.867	0.685	0.828
ATT[d]	ATT1	0.948	—	—	—
	ATT2	0.955	—	—	—
	ATT4	0.920	0.959	0.886	0.941
PE[e]	PE1	0.971	—	—	—
	PE2	0.970	—	—	—
	PE3	0.942	0.973	0.924	0.961
SAT[f]	SAT1	0.793	—	—	—
	SAT2	0.837	—	—	—
	SAT3	0.875	—	—	—
	SAT4	0.853	0.905	0.706	0.840
BIU[g] the system	BIU1	0.975	—	—	—
	BIU2	0.975	0.975	0.951	0.975

[a]AVE: average variance extracted.
[b]PEOU: perceived ease of use.
[c]Not applicable.
[d]ATT: attitude.
[e]PE: perceived enjoyment.
[f]SAT: satisfaction.
[g]BIU: behavioral intention to use.

For the discriminant validity, the squared root of the AVE value for each construct was compared with the correlations between the construct and other latent variables. The results suggested that the coefficients of √AVE were all greater than other correlations' Pearson r, which suggests a good discriminant validity for the outer model ([28]; see Table 3). The resulting variance inflation factors also suggested that no significant colinear relationship was identified.

Table 3. Correlation coefficients for discriminant validity.

Construct	PEOU[a]	ATT[b]	PE[c]	SAT[d]	BIU[e]
PEOU	0.828	—[f]	—	—	—
ATT	0.521	0.941	—	—	—
PE	0.440	0.808	0.961	—	—
SAT	0.214	0.609	0.618	0.840	—
BIU	0.218	0.634	0.549	0.603	0.975

[a]PEOU: perceived ease of use.
[b]ATT: attitude.
[c]PE: perceived enjoyment.
[d]SAT: satisfaction.
[e]BIU: behavioral intention to use.
[f]Not applicable.

Given that the coefficient of standardized root mean squared residual, an index of model fit in SmartPLS 3, was less than .08 (.076 for the structural model and .079 for the estimated model), the data fit the model well [30]. Afterward, the inner model was created applying SmartPLS 3's PLS algorithm. All the path coefficients can be seen in Figure 5. To test their level of statistical significance, a bootstrapping algorithm was calculated 5000 times in the software, as suggested by Hair et al [31]. The results showed that 4 out of 7 path coefficients were statistically significant at a *P* level of .05. One path was marginally significant at a *P* value of .10 (*P*=.07), and the other 2 paths were close to marginally significant (*P*=.11 and .12; see Table 4). The entire model explained 47.7% of the variance of BIU (including and excluding the control variables for groups for BIU: 48.6% and 47.7%, respectively), which is considered moderately explanatory [32].

Figure 5. The partial least squares structural equation modeling structural model for the acceptance of our virtual reality–assisted mental rotation training system. ATT: attitude; BIU: behavioral intention to use; PE: perceived enjoyment; PEOU: perceived ease of use; SAT: satisfaction.

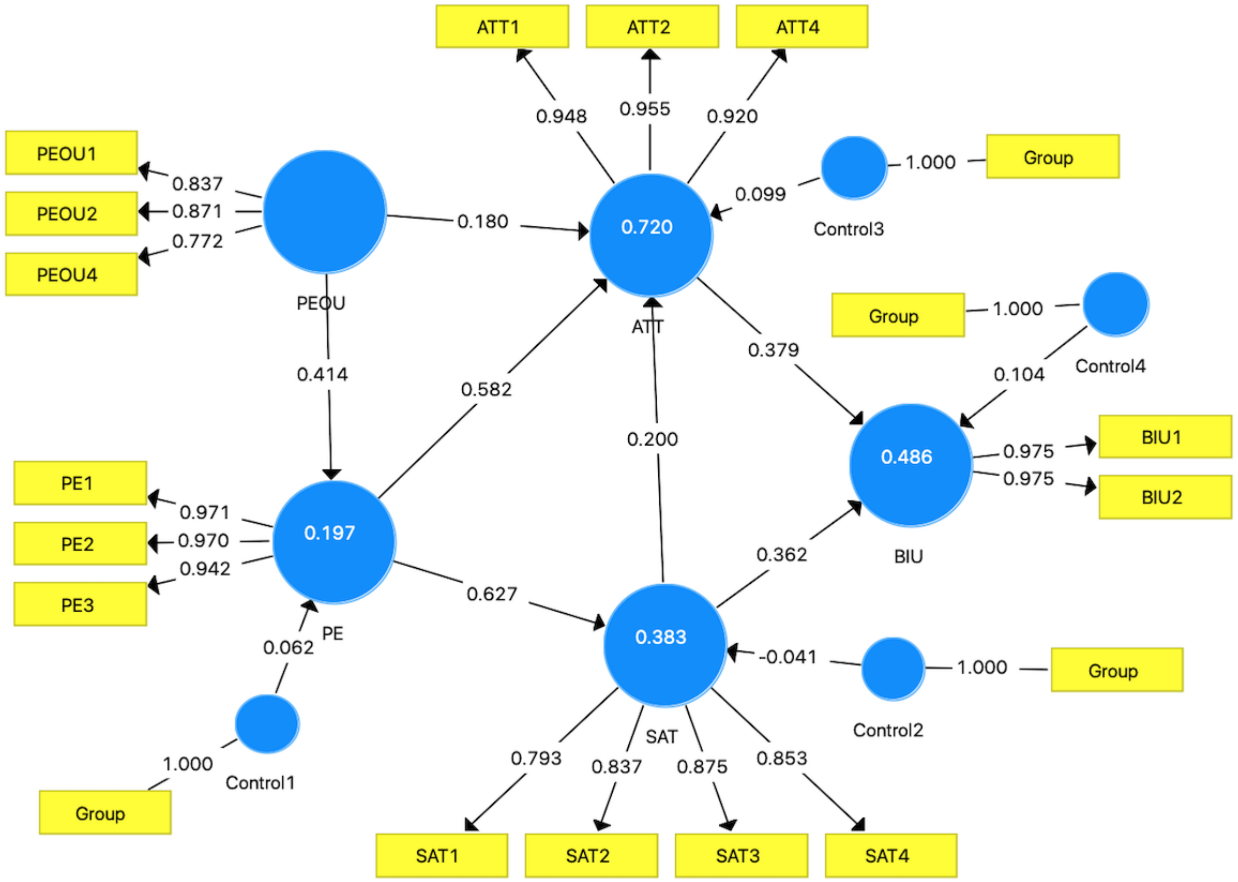


Table 4. Coefficients for the bootstrapping results.

Path	Original beta (O)	Sampling beta	SD	T (O/SD)	*P* values
ATT[a]–>BIU[b]	.379	.378	0.187	2.028	<.05
PE[c]–>SAT[d]	.627	.634	0.085	7.398	<.001
PE–>ATT	.582	.563	0.141	4.136	<.001
PEOU[e]–>ATT	.180	.185	0.112	1.614	.11
PEOU–>PE	.414	.442	0.141	2.943	<.01
SAT–>ATT	.200	.213	0.128	1.567	.12
SAT–>BIU	.362	.359	0.199	1.819	<.10

[a]ATT: attitude.

[b]BIU: behavioral intention to use.

[c]PE: perceived enjoyment.

[d]SAT: satisfaction.

[e]PEOU: perceived ease of use.

To better understand how each construct interacted with other variables in the model, indirect effects (mediations) were also examined based on a 5000-time bootstrapping sample. As can be seen from Table 5, all indirect effects (including specific paths) for endogenous variables were exported and compared. Regarding the indirect effect on the variable of SAT, PE significantly mediated the influence of PEOU on SAT (beta=.259). For the construct of ATT, the indirect effect via the path PEOU–>PE–>ATT significantly mediated the effect of PEOU on ATT (beta=.241). For BIU, PE and PEOU's effects were both significantly mediated by other variables (beta=.495 and beta=.273). Specifically, PE's effect on BIU consisted of the marginally significant paths of PE–>ATT–>BIU (beta=.220) and PE–>SAT–>BIU (beta=.227).

Table 5. Mediation effects (indirect effects).

Construct	Direct effects		Indirect effects		Specific paths	Specific effects	
	Beta value	*P* value	Beta value	*P* value		Beta value	*P* value
SAT[a]							
PEOU[b]–>SAT	—[c]	—	.259[d]	.005	PEOU–>PE–>SAT	.259[d]	—
ATT[e]							
PE[f]–>ATT	.582[g]	<.001	.126	.19	PE–>SAT–>ATT	.126	—
PEOU–>ATT	.180	.11	.293[h]	.01	PEOU–>PE–>ATT	.241[h]	—
—	—	—	—	—	PEOU–>PE–>SAT–>ATT	.052	—
BIU[i]							
PE–>BIU	—	—	.495[g]	<.001	PE–>ATT–>BIU	.220[j]	.05
—	—	—	—	—	PE–>SAT–>BIU	.227[j]	.08
—	—	—	—	—	PE–>SAT–>ATT–>BIU	.048	—
PEOU–>BIU	—	—	.273[d]	.002	PEOU–>ATT–>BIU	.068	—
—	—	—	—	—	PEOU–>PE–>ATT–>BIU	.091	—
—	—	—	—	—	PEOU–>PE–>SAT–>BIU	.094	—
—	—	—	—	—	PEOU–>PE–>SAT–>ATT–>BIU	.020	—
SAT–>BIU	.362[j]	.07	.076	.31	SAT–>ATT–>BIU	.076	—

[a]SAT: satisfaction.
[b]PEOU: perceived ease of use.
[c]Not applicable.
[d]$P<.01$.
[e]ATT: attitude.
[f]PE: perceived enjoyment.
[g]$P<.001$.
[h]$P<.05$.
[i]BIU: behavioral intention to use.
[j]$P<.10$.

Discussion

Key Findings and Theoretical Discussion

This study created a theoretical model to examine how determining factors from relevant theories of technology acceptance can be used to explain the acceptance of a novel VR-assisted MR training system created by our research team. The results suggested that ATT affected BIU (beta=.379; H2). This finding is consistent with the TAM [1]. We also found that PEOU's effect on ATT was mediated by PE (beta=.241). The indirect effect of PEOU on BIU was mediated by other variables in the model (beta=.273). PEOU has been a crucial factor affecting users' acceptance of information systems. In our study, it is likely that applying VR technology to both the hardware and software of the MR training system was relatively new and novel to the trainees. As most users were new to the VR system, they were not that familiar with its usage compared with other information technology they use in their everyday lives. Therefore, PEOU served as the predictive factor for their ATT toward and intention to use the VR-assisted MR training system. Whenever trainees perceived the use of our MR training system as easier, they had a better ATT toward the system and a higher intention to use it. By examining the key constructs' direct and indirect effects, our study extended the current TAM theory from the context of information technology and systems to VR educational technology and further expanded the findings from recent applications of TAM in other VR-assisted systems (eg, [11,12]).

In addition, this study replicated the finding of the study conducted by Davis et al [13] that PE was affected by PEOU (beta=.414; H3). That is, trainees who regarded the MR training system as more effortless to use would perceive a higher level of enjoyment. In contrast, whenever users felt that using the system was challenging, their PE decreased. Furthermore, our study suggested that PE not only served as a variable that is influenced by PEOU but also served as the mediator between PEOU and other constructs in the model. Specifically, PE mediated the effect between PEOU and SAT (beta=.259) and partially mediated the effect of PEOU on ATT (beta=.241). Other than these findings, our study also verified that PE affected ATT (beta=.582; H4) and SAT (beta=.627; H5), as we had hypothesized. Those trainees who perceived a higher level of enjoyment had a more positive ATT toward and SAT with the system.

Extending the finding from the study by Davis et al [13] that PE played the predictive role in BIU and actual use, this study showed that PE affected BIU, mediated by ATT and SAT, specifically with the paths of PE–>SAT–>BIU (beta=.227) and PE–>ATT–>BIU (beta=.220). Users' PE first affected their SAT with and ATT toward the system, which later influenced their intention to use the system. Our study, thus, extended Davies' suggested psychological relationship between joyful perception and behavioral intention by adding 2 attitudinal factors, ATT and SAT, between them. In other words, a chain relationship, joyful perception–>attitudinal factors–>behavioral intention, was created. This study suggested the importance of ATT and SAT as the mediators when considering PE's influence on BIU.

Finally, aligning with the ECM [16], we found that trainees' SAT with the MR system directly predicted their intention to use it (beta=.362; H7). Whenever the VR-assisted training system satisfied the users, they were likely to adopt it for learning. SAT, thus, also played a mediating role between PE and BIU (beta=.227), as discussed in the previous paragraph.

Practical Implications

On the basis of the findings of this established model, we also provide practical implications for MR trainers, technology developers, and education professionals. The empirical evidence of this study suggested that trainees' intention to use the novel VR-assisted interactive MR training system was predicted by their PEOU and PE (indirectly via ATT or SAT). Given that the use of an MR training system enhances trainees' MR ability [2], suggestions for technology developers and educators based on the previous 2 exogenous factors are discussed and aimed at helping relevant professionals better apply VR-assisted technologies and systems for education.

The predictive role of PEOU suggests that a user-friendly design is necessary for a VR-assisted MR training system. This requirement is understandable, as VR technology is relatively new and novel to consumers when compared with other information technology and systems on the market. VR technology developers are encouraged to keep improving system's ease-of-use function, specifically with its hardware (eg, stereoscopic glasses and display and interactive controller), as well as the interactive design between the users and MR objects via the controller in the virtual environment. Future systems might want to consider eliminating tools and use of a physical controller and instead develop a motion sensor to completely rely on the trainees' gestures or body movements to interact with the virtual content. These suggested approaches could effectively increase trainees' PEOU, which would eventually lead to their better intention to use the training system.

PE, as we had predicted, served as the predictive factor for the use of the MR training system. We suggest that technology developers might further develop a system that complements the VR head-mounted display (HMD) that completely separates the real and virtual environments. An HMD could further create a better spatial presence by allowing users to actively switch their field-of-view rather than passively observe the content [33]. Previous studies found that whenever spatial presence increased, observers' enjoyment amped up accordingly [34,35], as cited in the paper by Ravaja et al [36]. For the tasks of MR training, game scenarios such as stereoscopic 3D interactive Tetris could be created, which would likely be more playful for users. It is clearly supported by previous studies on digital learning (eg, [37,38]) that users in a game-playing situation perceived increased enjoyment.

Limitations and Future Research

Similar to other studies, this research has its limitations and needs future research to further gauge unanswered questions. First, although all the causal hypotheses were based on established theories and previous studies, the nature of the data for our proposed theoretical model is cross-sectional. Future studies capable of conducting experiments are encouraged to investigate the relationships between the constructs explored in our model. Furthermore, this study explored the acceptance level of VR's educational application in the context of MR. Other educational and training activities, which might apply VR technology in slightly different ways, are also worth further exploration. These extended studies would help researchers and practitioners have a holistic understanding regarding how VR technology can be accepted for educational purposes. Finally, although our proposed theoretical model explained nearly half (47.7%) of the variance of BIU, other VR-specific factors on trainees' use of the novel VR-assisted interactive MR training system, such as perceived simulation and presence, need to be developed and incorporated into the model to better comprehend the remaining unanswered variance for adoption intention.

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Conflicts of Interest

None declared.

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Abbreviations

ATT: attitude
AVE: average variance extracted
BIU: behavioral intention to use
dof: degree-of-freedom
ECM: expectation-confirmation model
HMD: head-mounted display
MR: mental rotation
PE: perceived enjoyment
PEOU: perceived ease of use
PLS-SEM: partial least squares structural equation modeling
PU: perceived usefulness
SAT: satisfaction
SEM: structural equation modeling
TAM: technology acceptance model
VR: virtual reality

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Original Paper

Using String Metrics to Improve the Design of Virtual Conversational Characters: Behavior Simulator Development Study

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Abstract

Background: An emergency waiting room is a place where conflicts often arise. Nervous relatives in a hostile, unknown environment force security and medical staff to be ready to deal with some awkward situations. Additionally, it has been said that the medical interview is the first diagnostic and therapeutic tool, involving both intellectual and emotional skills on the part of the doctor. At the same time, it seems that there is something mysterious about interviewing that cannot be formalized or taught. In this context, virtual conversational characters (VCCs) are progressively present in most e-learning environments.

Objective: In this study, we propose and develop a modular architecture for a VCC-based behavior simulator to be used as a tool for conflict avoidance training. Our behavior simulators are now being used in hospital environments, where training exercises must be easily designed and tested.

Methods: We define training exercises as labeled, directed graphs that help an instructor in the design of complex training situations. In order to increase the perception of talking to a real person, the simulator must deal with a huge number of sentences that a VCC must understand and react to. These sentences are grouped into sets identified with a common label. Labels are then used to trigger changes in the active node of the graph that encodes the current state of the training exercise. As a consequence, we need to be able to map every sentence said by the human user into the set it belongs to, in a fast and robust way. In this work, we discuss two different existing string metrics, and compare them to one that we use to assess a designed exercise.

Results: Based on the similarities found between different sets, the proposed metric provided valuable information about ill-defined exercises. We also described the environment in which our programs are being used and illustrated it with an example.

Conclusions: Initially designed as a tool for training emergency room staff, our software could be of use in many other areas within the same environment. We are currently exploring the possibility of using it in speech therapy situations.

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KEYWORDS

spoken interaction; string metrics; virtual conversational characters; serious games; e-learning

Introduction

Virtual Conversational Characters

The field of virtual conversational characters (VCCs) is an emerging research field that is growing in importance, both in industrial and academic applications. Our company started to include VCCs as a component of our simulators in 2014, mainly oriented to military and police environments, and recently it was proposed to migrate this type of simulator to hospital environments.

VCCs, also known as embodied conversational agents by Poggi et al [1], are 2D and 3D models of real persons that must be capable of human-like behavior. Apart from high-quality graphics, the most important characteristics that define VCCs are as follows:

1. Degree of embodiment: a full embodiment implies rendering a complete body. A talking head is an example of partial embodiment.
2. Believable talking: the VCC must be able to maintain a conversation with the human user. The most difficult problem to solve is to manage communication in a way that the human user does not perceive his or her dialogue partner as an emotionally numb agent.
3. Gesturing: nonverbal behavior is key when trying to solve the traditional lack of naturalness of VCCs. Nonverbal behavior can be introduced in one or both of the following ways:
    a. Facial gesture: different models and taxonomies for facial movement have been proposed by Ekman and Friesen [2] and Martinez and Shichuan [3]. An excellent state of the artwork on facial expressions for VCCs is that of Ochs et al [4].
    b. Body gesture: this usually involves hand and arm movements while talking, as included by Hartholt et al [5] in the virtual human toolkit.
4. Emotional behavior of the character: for a VCC, it is desirable not only to be able to maintain a conversation, but also to do so while showing some kind of personality, mood, or attitude.

In this work, we focus on the dialogue management problem. Involving a VCC in a meaningful conversation often implies huge knowledge databases, syntactic and semantic analysis, and the use of artificial intelligence techniques to achieve a convincing result. Designing conversational situations as graphs in the way described in García et al [6], we restrict the possible states of the dialogue, the sentences to be said by the VCC, and the sets of sentences that it will understand. This method does not decrease the applicability of our behavior simulator, as it is intended to be used in strictly constrained situations. Unfortunately, two problems arise when using such an approach: (1) the need for a huge number of similar but slightly different sentences to be said by the VCC if we want the agent not to appear too repetitive and (2) on the other hand, we want the VCC to be able to understand an order, question, or command expressed in as many ways as possible.

The first problem can be solved merely by including a high number of different ways to express what the VCC is going to say and by randomly picking one of them at execution time. The second problem requires the mapping of the expressions said by the human user to any of those the VCC can accept, converting it into the associated label, and delivering it to the situation manager, all within the execution time. This is where string metrics come into play, as a way of measuring the similarities between sentences said by the human user and the sets of expressions the VCC is expecting.

Related Work

Related works include Rosmalen et al [7], where an existing serious game is extended to include a chatbot, as well as those related to the formalization and use of behavior trees by Johansson and Dell’Acqua [8], Isla [9], or Imbert and de Antonio [10], where COGNITIVA is proposed as an emotional architecture for VCCs. The most closely related works to that reported here are those of Hartholt et al [5] and Morie et al [11], where the virtual human toolkit is described. More recently, a framework for the rapid development of Spanish-speaking characters has been presented in Herrera et al [12].

In this context, our system's characteristics are as follows:

1. Full embodiment: our VCCs are complete human models rendered inside a realistic 3D scene.
2. We solve the dialogue management problem by defining our training situations as graphs and by introducing a statistical process of strings returned by the speech recognition library as a way of directing the evolution of the exercise.
3. Inclusion of a facial action code system, as described by Ekman and Friesen [2], as a way of manipulating the VCC's facial gesture.
4. Emotional behavior is based on an emotional engine that permits the design and testing of the underlying personality of the VCC, described in García et al [6], and is mainly oriented to the simulation of violent behaviors, as this has been the main application field of our software.

The rest of the paper is structured as follows:

1. The Environment section describes the context where string metrics are being used.
2. In the Situation Graphs section, we describe the component of the behavior simulator to be analyzed using string metrics.
3. The String Metrics section is devoted to the explanation of some string metrics and their comparison to the one we are using.
4. In the Graph Validation section, three different string metrics are applied to an example graph using our graph validation tool.
5. Finally, in the Conclusions and Future Work sections, we present the main achievements of our work and some possible future lines of research.

Methods

Environment

In this section, we describe the context in which we are using string metrics. Our simulators are designed to be used in conflict avoidance training contexts, including situations where a member of the security staff must ask a suspect for his or her identity card, begin the initial evaluation process of a patient, or deal with an annoyed relative. Such situations are characterized by the fact that there is a clear policy the trainee must follow in order to fulfill the exercise. Conversely, the VCC will have a small set of expected behaviors. Therefore, we need to build a believable VCC that is able to communicate in a clearly constrained scene.

Our tool lets the user give a formal description of the training exercise. The output of the tool is a directed graph in Graphviz format, following the description of Emden and North [13], that represents the current and possible states of the exercise and defines transitions from one state to another, in terms of the labels associated with each arc. The main components of our behavior simulator are as follows:

1. A situation graph, defining the exercise.
2. A set of sentences associated with each node of the graph. Whenever the situation enters a state, the system will randomly pick one of the sentences associated with that node. The higher the number of sentences, the lower the probability of repeating a sentence, while increasing the perception of talking to a real human.
3. One or various sets of sentences that the VCC must recognize when the graph is in a valid state.

Each node in the graph will be connected to one or more other nodes. The arcs representing these connections will be labeled with names like *Ask_For_ID*, which require an action from the human user. Each label will be associated with a set of sentences that the human user can say in order to trigger that transition. We keep this kind of information stored in files sharing the *.lang* extension. The other elements of the system are as follows:

1. An emotional engine that drives the emotional state and behavior of the VCC, as described in García et al [6].
2. A body language interpreter that is developed using the Microsoft Kinect sensor, which analyzes the body gesture of the human interacting with the simulator, in order to give advice about good or bad practices while interacting with real humans.

Situation Graphs

Any one of our situation graphs will contain, at least, the following states:

1. Init: in this state, the system performs some basic tasks, such as graph file parsing, audio and graphical setup, and some initial calculations that increase performance, which will be explained in the Histogram Matching section.
2. Success: this state will be reached when the human performing the training exercise completes it in a satisfactory manner.
3. Failure: the opposite of the Success state.

In order to clearly state the role of the situation graph, we will describe an unreal, simple training situation with its associated states and sets of sentences. Describing a medical interview in terms of one of our situation graphs generates a huge image, too big for the illustrative purposes of this section.

We have a situation where the behavior simulator, once initialized, will present the user with a VCC. The goal is to obtain their identification card, to avoid the start of a fight, or to prevent the individual from running away from the scene. The situation graph is shown in Figure 1.

Associated with each state in the graph are a stored set of sentences that the VCC will keep saying until the answer received from the user triggers a transition to another state. The system stores these sets in files named after the state they are associated with; all of them share the *.talk* extension in their file names. Based on the contents of the *.talk* files, the behavior simulator will keep the VCC saying a sentence picked at random from those associated with the current active node of the situation graph. The behavior simulator will also try to map what the human user says into the labels that can trigger a transition from the current state to any other.

At the moment of writing this paper, we have designed four different training situations, or exercises, each with their own learning goals:

1. A lost child in the waiting room: the goals are to discover where the child came from and what she is doing at the hospital.
2. An aggressive young man under the influence of drugs: the goal is to gain time while security personnel arrive.
3. An elderly woman with cognitive impairment: the goals are to make an initial assessment of the woman's condition and to reassure her.
4. A nervous young lady asking for information about one of her relatives: the goal is to convince her to leave the area and retire to the waiting room.

Figure 2 shows the system a moment after starting one of these training exercises. The system can be run in silent mode, showing sentences said by the VCC only on the screen in text, and the microphone can be disconnected to allow input of sentences using the keyboard.

Figure 1. Simple situation graph. Init: the state in which the system performs some basic tasks. Success: this state will be reached when the human performing the training exercise completes it in a satisfactory manner. Failure: the opposite of the Success state. *Regular_Chat*: as soon as the exercise starts, the scene enters this state, with the virtual conversational character (VCC) engaging in small talk. *Asked_ID*: the situation enters this state if the user says one of the sentences associated with the *Ask_For_Identification* label; when in this state, the VCC will probabilistically decide to collaborate or not, showing ID, or returning to *Regular_Chat*. The former means reaching the Success state. The latter means that the VCC refused to obey and show their ID card. In practice, this implies remaining in the same state, *Regular_Chat*. *Buying_Time*: if the user does not ask for identification, the scene enters a dumb state, with the VCC trying to escape. If the user continues asking for ID, the situation reaches an impasse. To return to *Regular_Chat*, the security guard must warn the VCC about trying to escape. Any other kind of conversation triggers a Failure.

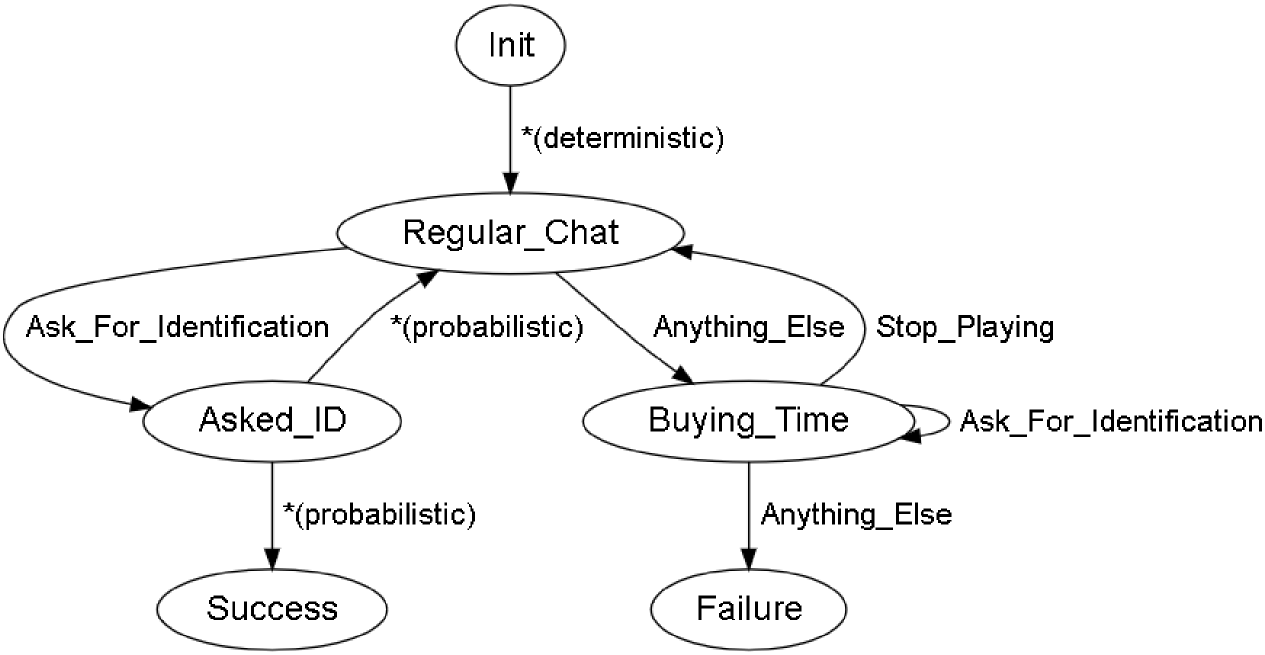


Figure 2. A user facing the system a moment after starting a training exercise.

String Metrics

Overview

In order to trigger transitions from one state of the graph to another, we need some kind of metric to evaluate the distance between the string returned by the speech recognition library and all the strings that are acceptable for the current state. There is a large number of metrics that can be used to measure the difference between pairs of strings. In this section, we compare two different well-known metrics—that proposed by Levenshtein [14] and the Gestalt pattern-matching algorithm proposed by Ratcliff and Metzener [15]—when used for our purposes and justify the use of our own metric, which we will call histogram matching.

String distance functions or string similarity metrics are defined between two strings, for example, s and t. Distance functions map a pair of strings s and t to a real number r, where a smaller value of r indicates greater similarity between s and t. Similarity functions are analogous to distance functions, except that larger values indicate greater similarity.

Levenshtein Distance

One important class of distance functions are edit distances, in which distance is the cost of the best sequence of edit operations that converts s to t. Typical edit operations are character insertion, deletion, and substitution, and each operation much be assigned a cost. Levenshtein distance is defined in Levenshtein [14]. However, even in its normalized version proposed by Yujian and Bo [16], it is not useful for us, as it gives high values to pairs of strings that are a word-by-word permutation of the original, for example, “Don't resist, please” and “Please, don't resist.” See Table 1 for results.

Table 1. Levenshtein distances for the strings s1, s2, and s3.

String	String, Levenshtein distance		
	s1[a]	s2[b]	s3[c]
s1	0	14	14
s2	14	0	16
s3	14	16	0

[a]s1: “Please show me your ID.”
[b]s2: “Show me your ID please.”
[c]s3: “Your ID. Show it to me.”

Gestalt Pattern Matching

Ratcliff and Metzener’s pattern-matching algorithm [15] has been described as a wild-card search process without wild cards. The algorithm builds its own wild cards, based on the matches found between two strings, s and t. First, the algorithm examines s and t and locates the largest common subsequence between them. It then uses this group of characters as an anchor between s and t. Any group of characters found to the left or the right of this anchor is placed on a stack for further examination. The procedure is repeated for all substrings on the stack until it is empty.

The returned value is twice the number of characters found in common, divided by the total number of characters in the two strings; the score is returned as an integer, reflecting a percentage match. We are currently using the SequenceMatcher version of Ratcliff's algorithm, included in the difflib package from Python, version 3.7 (Python Software Foundation), that returns a real number instead.

Histogram Matching

We will now describe the numerical procedure that lets us assign a label to any string returned from speech recognition libraries, such as Microsoft Speech Application Programming Interface (API). When the exercise starts, we take each *.lang* file, and for each sentence we perform the following procedure (see Figure 3, Equation 1):

1. Convert the sentence to lowercase letters, discarding any punctuation marks.
2. Calculate the number of letter “a”s, “b”s, etc, that the sentence contains. This array is what we call a letter histogram. Letter histograms for every single possible sentence that the human user can potentially say are calculated and stored before the exercise starts.
3. Let h(c)s be the number of occurrences of character c inside string s.
4. Let T(s) be the sum of $h(c)_s$ for each possible value of c inside string s.

When the exercise starts, we need to know the distance between the words said by the human user as well as all the sentences stored inside the *.lang* files. We define the histogram-matching function between strings s and t as expressed in Equation 2 (see Figure 3). In the histogram-matching formula (see Figure 3, Equation 2), s represents the sentence said by the human user, and t is each one of the sentences included in the *.lang* files that is associated with outgoing arcs from the current active node in the situation graph. The maximum of these values determines the label we assign to the sentence that was said and, eventually, a transition to another node inside the graph.

In Equation 3 (see Figure 3), set (t) is a function returning the set that t belongs to, and $set(t)$ is an outgoing arc.

Figure 3. Equations for our histogram-matching metric.

Equation 1: $$T(s) = \sum_{c='a'}^{c='z'} h(c)_s$$

Equation 2: $$HM(s,t) = 100.0 * \left(1 - \frac{\sum_{c='a'}^{c='z'} \|h(c)_s - h(c)_t\|}{T(s) + T(t)}\right)$$

Equation 3: $$Label(s) = set(max\{HM(s,t)\forall t\})$$

Results

Data Evaluation

In this section we describe the results obtained when applying the three string metrics described in the Methods section to a set of sentences, and the process that we follow to validate a graph.

Levenshtein Distance

Table 1 shows the value of Levenshtein distance for three different strings—s1, s2, and s3—with s2 being a word-by-word permutation of s1, and being very similar to s3, at least semantically. The strings s1, s2, and s3 stand for “Please show me your ID,” “Show me your ID please,” and “Your ID. Show it to me,” respectively.

As we do not process commas, nor any other punctuation marks, s1 and s2 should be equivalent sentences for our system, and the distance between s3 and the others should be minimal. We are showing not-normalized values here, but it can be seen that the distance between s1 and s2 is not equal to zero, forcing us to include all the valid permutations of a sentence in the respective *.lang* file if we want the VCC to understand all of them. This renders the Levenshtein distance metric inappropriate for our labeling needs.

Gestalt Pattern Matching

Table 2 shows the values of the Gestalt pattern-matching algorithm by Ratcliff and Metzener [15] when applied to s1, s2, and s3. It returns a 100% similarity value over the main diagonal, as expected, but the reported value is not symmetric for s2 and s3. Additionally, it gives a similarity value of 68% between s1 and s2, too low for a pair of sentences that must be considered equivalent for our system.

Table 2. Python SequenceMatcher similarities for the strings s1, s2, and s3, based on the Gestalt pattern-matching algorithm.

String	String, SequenceMatcher similarity		
	s1[a]	s2[b]	s3[c]
s1	100.0	68.18	32.55
s2	68.18	100.0	41.86
s3	32.55	46.51	100.0

[a]s1: “Please show me your ID.”

[b]s2: “Show me your ID please.”

[c]s3: “Your ID. Show it to me.”

Histogram Matching

Table 3 shows histogram-matching values between the strings s1, s2, and s3. The main diagonal values are 100%, as expected, but we also see total similarity between s1 and s2. Reported similarity between s1 and s3, and between s2 and s3, is higher than 70%, which is far from being an almost complete match, but significantly higher than the value reported by the Gestalt pattern algorithm (32%).

Figures 4 and 5 show the letter histograms associated with every sentence included inside the *Stop_Playing.lang* and *Ask_For_Identification.lang* files.

The example has been intentionally kept simple but practical, in order to explain how histogram matching works. Similarities between the different sentences associated with the same label (ie, inside the same set) present no practical problem. Problems arise when, for two different labels associated with arcs that come out of the same graph node, any of the sentences included in the corresponding files can be misunderstood as any of those defined for a different transition. In other words, the distance between each of the sentences included in any *.lang* file and those included in a *.lang* file whose initial graph node is the same, should be as large as possible, in order to have the least confusing exercise definition. Additionally, as a reinforcement factor, we also count the number of blank spaces included in the sentence, to avoid strange coincidences that would confuse the system.

In the exercise we are using as an example, there is only one situation to analyze—there are three different arcs coming out from the *Buying_Time* state, and we need the triggering sentences for these arcs to be as different as possible: (1) *Stop_Playing*, (2) *Ask_For_Identification*, and (2) *Anything_Else*.

Of these three transitions (ie, labels), only the first two are interesting, as *Anything_Else* is a special case that we will assign if it is not possible to assign any of the others, up to a defined tolerance. We mark this kind of label, leaving the corresponding *.lang* file almost empty, containing only a # symbol. Therefore, it is clear that the exercise would be ill defined if any sentence inside *Stop_Playing.lang* is too similar to any of the sentences included in *Ask_For_Identification.lang*. Our exercise validation tool analyzes this kind of situation and highlights potentially conflicting labels, sentences, and states. The example is analyzed in the Graph Validation section

Table 3. Histogram-matching similarities for the strings s1, s2, and s3.

String	String, histogram-matching similarity		
	s1[a]	s2[b]	s3[c]
s1	100.0	100.0	70.5
s2	100.0	100.0	70.5
s3	70.5	70.5	100.0

[a]s1: "Please show me your ID."

[b]s2: "Show me your ID please."

[c]s3: "Your ID. Show it to me."

Figure 4. Letter histogram for the *Stop_Playing.lang* file.

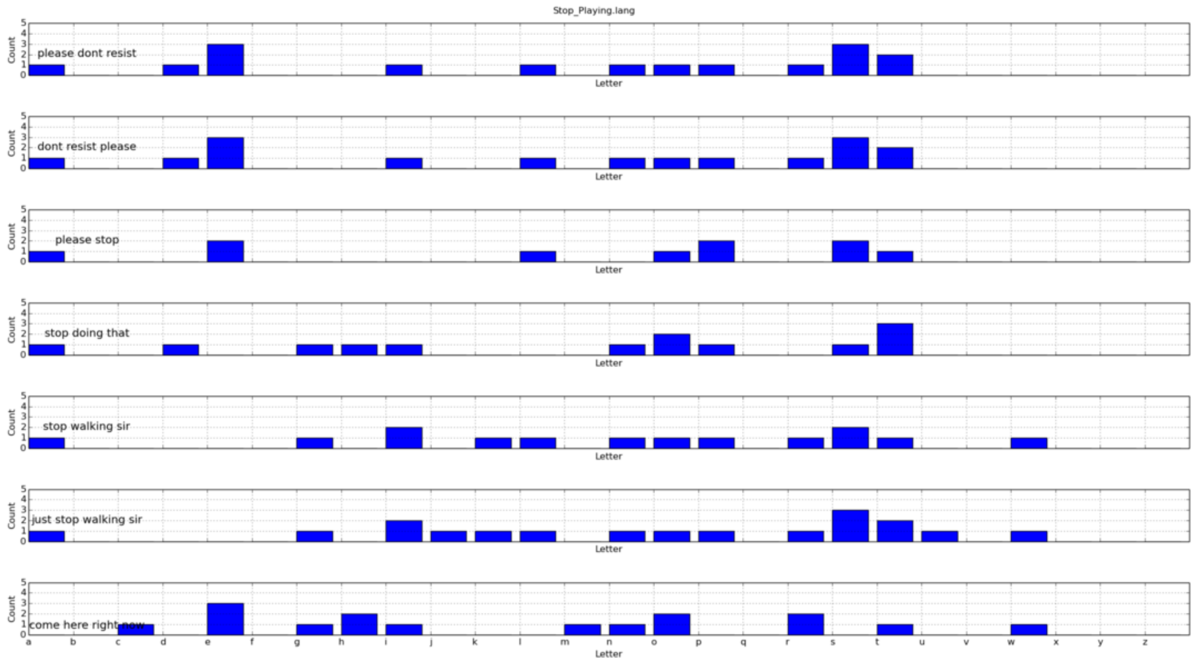
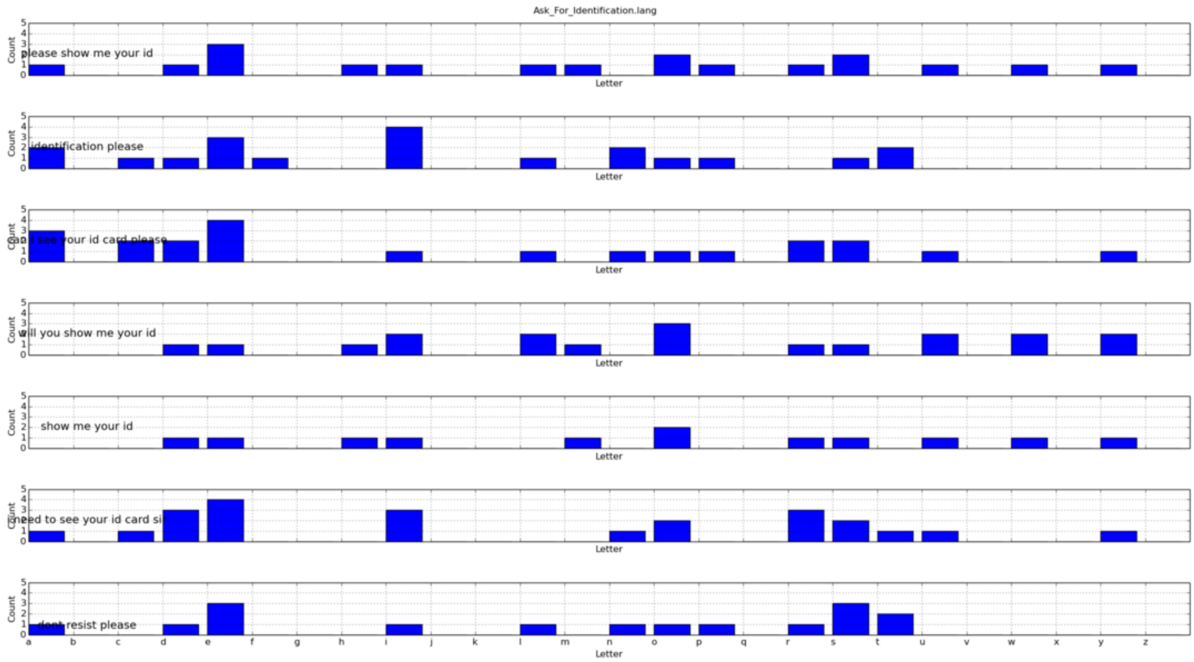


Figure 5. Letter histogram for the *Ask_For_Identification.lang* file.



Graph Validation

For the purpose of explaining how graph validation works, we intentionally added the following sentence to the *Ask_For_Identification* set file: "Don't resist, please."

Besides the lack of utility of such a sentence inside the file that stores different ways of asking a person for his or her hospital identity card, this sentence causes problems: when it is said by the human user, it would lead to ambiguity. In Figures 6 and 7, letter histograms for "Don't resist, please" and "Please, don't resist" are highlighted in red; this is not because of the absolute similarity between them, but because of their similarity to this extra sentence included in another *.lang* file, which would render the system unable to decide which transition is the correct one to be triggered.

The system informs us that sentences highlighted in red can confuse the situation manager when pronounced by the trainee. In this case, the solution is straightforward, as we have artificially generated the problem. The problem is solved simply by removing the extra sentence from the *Ask_For_Identification.lang* file. However, in more complex situations, the person in charge of the exercise design should look for alternatives.

After determining all the conflicting labels, our graph validation tool also marks in red each graph node with ill-defined outgoing arcs, helping in the identification and fixing of such problems. The output is a file in the Graphviz format: see Figure 8, where the graph for the working exercise is colored to highlight problematic nodes. An arc whose arrow is highlighted in red means that triggering transitions from the source state is not possible. Nonproblematic arcs are highlighted in green. The goal is to rewrite the sentences associated with each arc or to modify the graph definition of the exercise until no ambiguity is detected by the tool.

The use of the string metric defined in this paper is not mandatory. In fact, the user can choose one of the following string metrics and select the one that guarantees a better exercise definition to be used by the behavior simulator: (1) Levenshtein distance, as defined by Levenshtein [14], (2) Gestalt pattern matching [15], (3) histogram matching, as proposed in this paper, (4) Damerau-Levenshtein distance [17], or (5) Jaro-Winkler distance [18].

The explanation of each of these string metrics is outside the scope of this paper. In practice, we use the graph validation tool to choose a string metric that guarantees the absence of ambiguities when the simulator is running. If none of them can guarantee such a condition, the *.lang* files must be modified. The main window of the graph validation tool is pictured in Figure 9.

Figure 6. Processed histogram for the *Stop_Playing.lang* file.

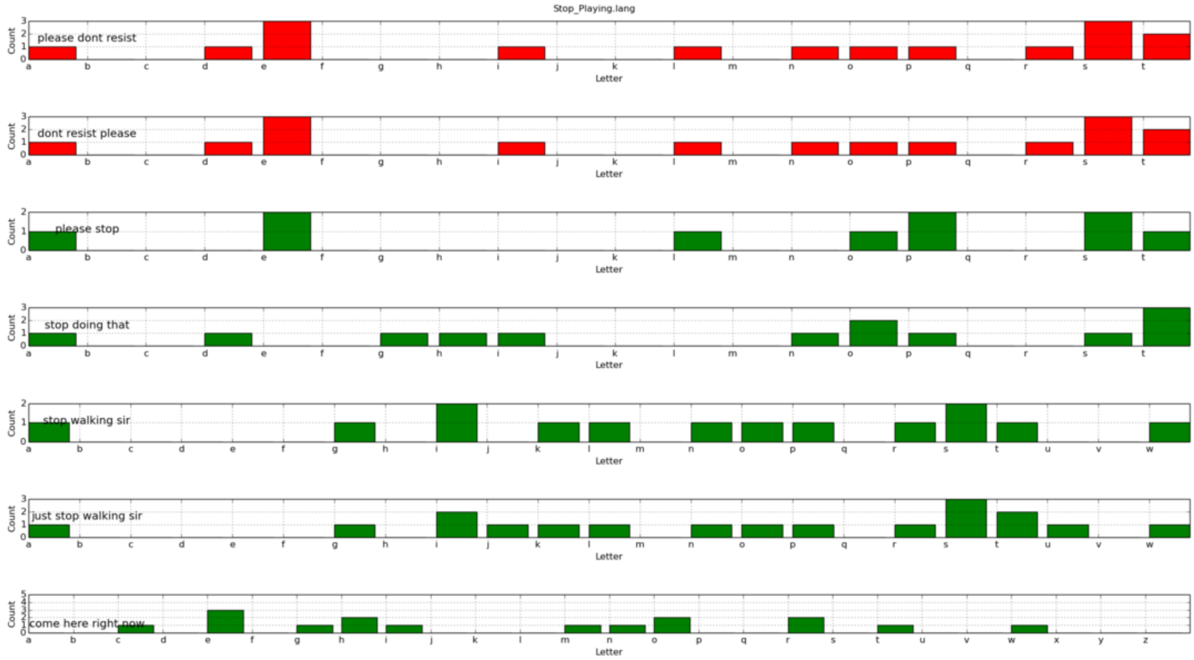


Figure 7. Processed histogram for the *Ask_For_Identification.lang* file.

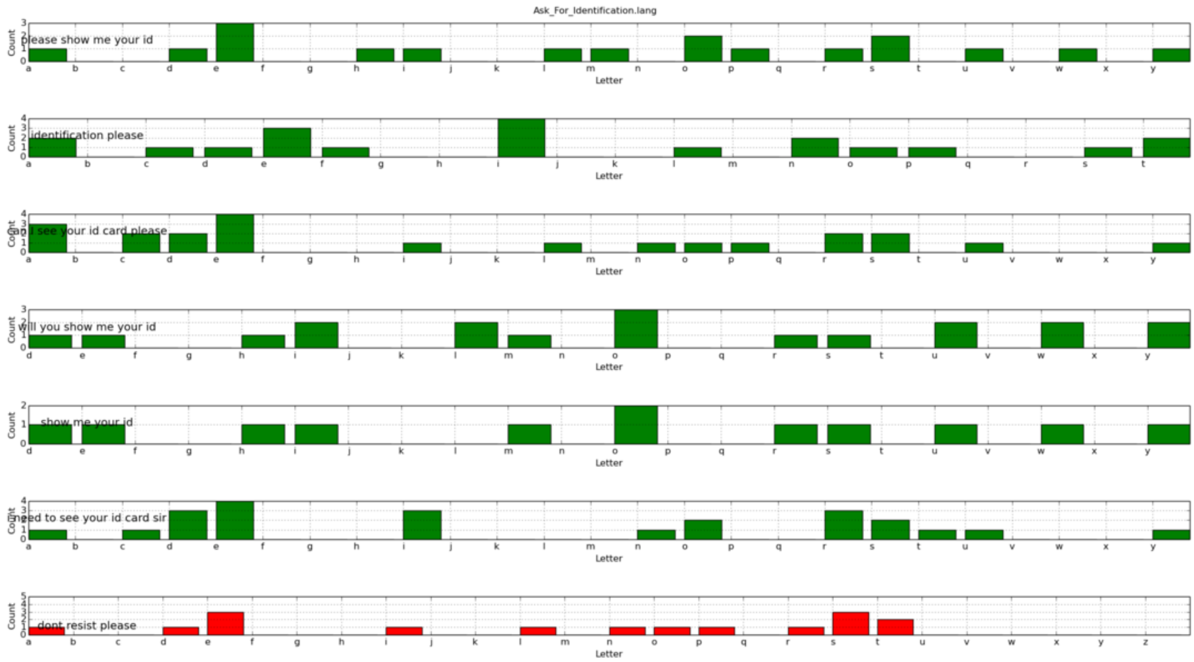


Figure 8. Validated graph. Init: the state in which the system performs some basic tasks. Success: this state will be reached when the human performing the training exercise completes it in a satisfactory manner. Failure: the opposite of the Success state. *Regular_Chat*: as soon as the exercise starts, the scene enters this state, with the virtual conversational character (VCC) engaging in small talk. Asked_ID: the situation enters this state if the user says one of the sentences associated with the *Ask_For_Identification* label; when in this state, the VCC will probabilistically decide to collaborate or not, showing ID, or returning to *Regular_Chat*. The former means reaching the Success state. The latter means that the VCC refused to obey and show their ID card. In practice, this implies remaining in the same state, *Regular_Chat*. *Buying_Time*: if the user does not ask for identification, the scene enters a dumb state, with the VCC trying to escape. If the user continues asking for ID, the situation reaches an impasse. To return to *Regular_Chat*, the security guard must warn the VCC about trying to escape. Any other kind of conversation triggers a Failure.

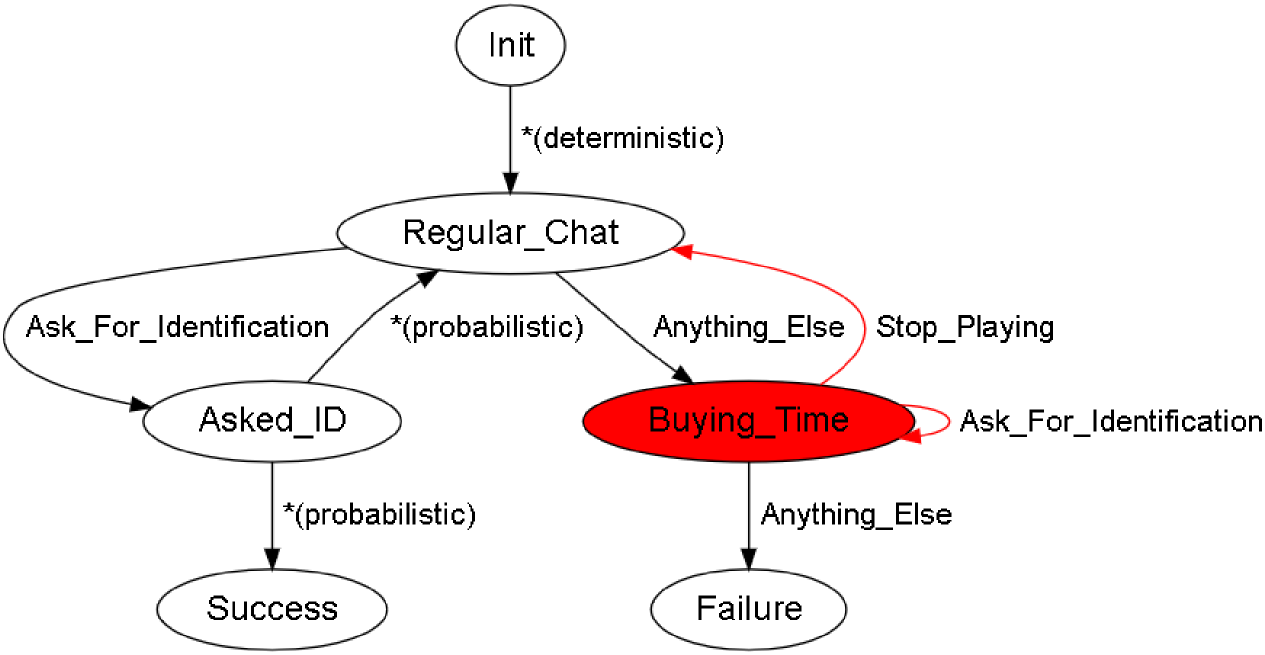


Figure 9. The main window of the graph validation tool. From this window, the user can (1) choose a Graphviz (.dot file) example to be analyzed, (2) obtain a graphic representation of the training exercise that it encodes, (3) select one of the available string metrics, (4) view letter histograms for each label, and (5) generate a .pdf file summarizing all the problems encountered during the analysis of the graph.

Discussion

We have developed a system for the fast design and testing of conflict avoidance situations, involving interactions between humans and VCCs. VCC-enhanced simulators present many advantages for multimodal communication, but also have the disadvantage of dealing with complex processes in order to provide effective verbal communication between VCCs and the human user. Speech recognition software is available and working, but we needed a way to assign labels to the outputs produced by these APIs. As the number of possible sentences to be recognized is potentially huge, even for a simple training exercise, we decided to use string metrics as a way of labeling. We have developed a tool that, after designing a training exercise, analyzes the sets of sentences associated with each transition inside the situation graph, highlighting potential signs of ill-defined exercises. The tool is also used to check the existence of all the files needed for the system to work properly before the exercise starts and to dynamically change some settings, such as the minimal matching confidence level required for a positive match, once the simulation has begun. This is useful for cases when the speech recognition library is not working properly, due to suboptimal acoustic conditions of the environment or incorrect vocalization by the human user.

After trying several existing string metrics, we decided to design one of our own: histogram matching. Histogram matching does this work for us at a reasonable speed, as half of the needed calculations are performed as soon as the training exercise is defined and before the whole system is running. The method is working correctly for the exercises we have defined to date. As a result, we can anticipate and solve design problems in the training exercise definition process and improve collaborative work between instructors and our development team.

For the future, we are planning the development of a module that automatically assigns violence levels to the sentences included inside *.lang* files, as a function of the kind of vocabulary employed. There is another feature that has not yet been implemented, which would be very useful in the exercise definition process. That is, being able to check the exercise without the whole graphics system working, running only the speech recognition and language synthesis modules, and allowing the interactive visualization of the active node of the situation graph, histogram-matching level, emotional state of the VCC, etc.

Our software was initially designed to help in the training of staff working for emergency services within a hospital. We think that it could also prove useful in speech therapy as a way of visually representing the differences between any goal sentence and what a human user actually says. We have identified some works using serious games in this field, such as Grossinho et al [19] and Cagatay et al [20]. In this sense, no structural modifications should be needed on our software, just a different philosophy in the design of the training exercises. That is to say, we have a VCC that the human must interact with. The goal would be to speak as correctly as possible in order to, for example, make the VCC do some work for us.

We also think that VCCs, in general, and our system, in particular, can be useful in helping patients make informed decisions when asked about the treatment plan they prefer, as discussed in Sherwin et al [21].

Conflicts of Interest

None declared.

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Abbreviations

API: application programming interface
VCC: virtual conversational character

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Original Paper

Learner Analysis to Inform the Design and Development of a Serious Game for Nongaming Female Emerging Health Care Preprofessionals: Qualitative Sample Study

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Abstract

Background: Overall, 75% of health care practitioners are women, but half of all females do not play digital games of any kind. There is no consensus in the literature regarding optimal design elements to maximize the efficacy of serious games. To capitalize on the promise of serious games in health care education, it is important for instructional designers to understand the underlying learners' values, attitudes, and beliefs that might motivate nongaming female health care preprofessional students to independently choose to persistently play serious games to mastery.

Objective: Specifically, the aim of this study was to seek answers to 2 questions. First, what values, attitudes, and beliefs contribute to the nongaming behaviors of 12th-grade female emerging health care preprofessionals? Second, how do the values, attitudes, and beliefs of 12th-grade female emerging health care preprofessionals align with important design features of serious games?

Methods: In this study, a learner analysis was conducted using semistructured interviews with 8 12th-grade college-bound female health science students to better understand learners' values, attitudes, and beliefs to inform the design and development of a serious game. These interviewees represented a diverse subset of the female emerging health care preprofessionals who self-identified themselves as not playing games at all, not very often, or infrequently.

Results: The findings suggest that the study participants exhibited a complex fusion of desire for both accomplishment and affiliation. The participants were all independent, competitive, and prosocial leaders. They thought strategically and consciously self-limited their leisure time to achieve personally meaningful long-term goals. They embraced overcoming expected failures and aimed to achieve relevant high-stakes wins in all academic, athletic, extracurricular, and leisure activities they valued while consciously avoiding what they considered to be non–goal-oriented activities.

Conclusions: The results of this study reinforce the need for a robust learner analysis to identify the multifaceted behavioral characteristics of targeted learners before the design and development of serious games. The common characteristics of the 12th-grade female health science students in this study suggest that they will choose to invest their limited leisure time playing a personally meaningful, preprofessionally authentic serious game if the collective design elements are aligned with the students' self-conceptualization of their present or future selves.

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KEYWORDS

games; health care; education; females; motivation; instructional design

Introduction

On the basis of the existing gender-based gaming research, half of all females do not play digital games of any kind [1-7]. This generalized finding is consistent with the digital game play consumption of female health science students. Kron et al reported that female medical students (N=115) played video games rarely (66%) or infrequently (22%), although 97% considered themselves to be basic to intermediate computer users [8]. More recently, the authors described similar results for a population of 17- and 18-year-old 12th-grade health science students (N=44) in which 56.7% of females (n=37) and 14.8% of males (n=7) reported that they did not play games at all or did not play very often. Notably, these female and male students reported that they used computers 86% and 57.1%, respectively, every day [9]. These findings are inconsistent with those of other researchers who suggest that young females who do not play digital games are somehow technologically disadvantaged [3,10]. All the young women (n=37) and men (n=7) in the authors’ study were college-bound science, technology, engineering, and mathematics (STEM) oriented students [9]. The number of females (84.1%), compared with males (15.9%), in this 12th-grade elective health science class was also consistent with the growing number of women in the health professions [9]. Overall, 75% of health care practitioners are women (N=9,420,000) [11]. Over 40% of physicians and surgeons now in the United States are females. Health care occupations, including pharmacists (63.4%), nurse practitioners (87.2%), physician assistants (72%), occupational therapists (86.8%), and physical therapists (69.5%), are primarily populated by women [11].

A robust targeted learner analysis should precede the design and development of any serious simulation-based or game-based educational intervention, but such analysis rarely occurs or is rarely reported [5,12-17]. The learner analysis described in this study was conducted to better understand the values, attitudes, and beliefs of 12th-grade female college-bound health science students before developing a serious simulation-based game for this population of students.

Background

The use of simulation in clinical education has been associated with positive results in the acquisition of knowledge, confidence, skills, attitudes, and behaviors for nearly 6 decades in modern health care contexts [18]. Simulation-based education provides opportunities for standardized, deliberate practice, with feedback for the correction of errors until reconstruction and encoding of new understandings are achieved. The use of simulation in clinical education approximates a dose-response relationship in which more practice results in increased knowledge, improved confidence, and improved skills [19]. Although the published dose-response results of learning outcomes in non–intervention-simulated settings are abundant and statistically impressive [20], research regarding the transfer and impact of new knowledge and skills gained in simulated settings to real-world clinical practice has been limited [21,22]. In reviews of simulation-based health care education research, only 14 papers, published between 2006 and 2013, reported the transfer of learning from a simulation laboratory, resulting in improved clinical care or better patient outcomes [23,24]. It has been suggested that integrating game elements into traditional simulation-based health science learning might improve students’ knowledge, skills, and performance transfer by triggering intrinsic motivation to choose self-persistence in learning [25]. However, in a systematic review of 42 serious games used to train health care professionals, only 1 reported the transfer of learning from the educational setting resulting in improved patient care [26]. The authors’ concluded that although serious gaming in medical education continues to establish itself, more work needs to be done to define best practices for its design, development, and evaluation. More recently, Kuipers et al [27] conducted an extensive systematic review of games and simulations for health care education and found none that included a cognizant design process focused on real-world transfer. A total of 12 of the 15 studies reviewed described subconscious design features that resulted in literal transfer and 3 studies that suggested figural transfer. The authors describe literal transfer as lateral real-world application and figural transfer as the application of new knowledge and skills across different problems or situations. The authors conclude that real-world transfer is mainly mentioned as a desired outcome in research related to games and simulations for health care education, not as a guide in the design process. They suggest that a conscious design rationale is needed to optimize the real-world transfer conditions.

At present, there is no consensus in the literature regarding optimal design elements to maximize the efficacy of serious games for health care education [28]. A serious game is generally described as an interactive digital game that is designed for an educational purpose that presents a challenge that a player needs to overcome to achieve an educational win state. In addition, player feedback is provided during game play (eg, points and penalties) to enable players to monitor their progress toward a win state [29]. Some authors include entertainment as a required design element of serious games, but others do not [28,30]. Other design elements such as narrative (story), competition or collaboration, chance (random events), and levels are often debated as either required or discretionary characteristics of serious games [12,29-32].

If the aim of instruction is to ultimately transfer new knowledge, skills, attitudes, and behaviors from health care academic settings to real-world application, simulation-based or game-based learning for the health professions must have a learner-centric design to facilitate intrinsic motivation so that students self-persist to achieve mastery [5,12,13,15-17]. To capitalize on the promise of serious simulation games in health care education, it is particularly important for instructional designers to understand the underlying values, attitudes, and beliefs that might motivate a predominantly female population of students to independently choose to persistently play to mastery.

Existing gender-based game research related to commercial hardcore and casual games can help serious game designers understand why the design elements of these popular games may alienate many female health science students. Hardcore video games are targeted for and predominantly consumed by males. Typical hardcore games such as *Grand Theft Auto* feature aggressive, competitive, and violent male protagonists who seek to achieve nonforgiving, high-stakes win states, often surrounded by hypersexualized secondary female characters who are either victims or damsels in distress [1,6,15,16,33-36]. In contrast to hardcore video games, casual video games such as *Diner Dash* and *FarmVille* are designed for and consumed predominantly by females. Typical casual games feature achieving forgiving low-stakes objectives in collaborative social settings and involve a manageable investment of small chunks of time in games that are easy to learn [1,35,37]. The stereotypical male/female binary design of such games should be avoided in the development of serious games for any prospective player whose motivation to play games may be much more nuanced [16,37]. Progressive and innovative serious game design should consider nonbiological masculine and feminine characteristics across race, ethnicity, socioeconomic position, nationality, and age. Designers should consider the target audiences' physiological reaction to visual, emotional, and tactile stimuli, and the situational cognitive-social context in which students will be exposed to the game should be understood before its development [5,12,15-17]. Finally, serious game designers need to understand the important affective parasocial connections that prospective players have with media characters in television (TV), movies, music, and books to promote engagement [5,38]. It has been suggested that the design of game characters' attributes that align with existing important affective parasocial media connections may result in greater player engagement through identification, representation, and a deeper sense of relatedness [5,38].

Study Purpose

In this study, semistructured individual interviews were conducted with 12th-grade female health science students who self-identified themselves as not playing games at all, not very often, or infrequently in a prior study by the authors [9]. It was expected that linking the existing gender-based gaming research with the results of these interviews might add a more richly detailed understanding that would inform the design and development of a serious simulation-based game that nongaming female emerging health care preprofessionals would be motivated to play. Specifically, the aim of this study was to seek answer to the 2 following questions:

- What values, attitudes, and beliefs contribute to the nongaming behaviors of 12th-grade female emerging health care preprofessionals?
- How do the values, attitudes, and beliefs of 12th-grade female emerging health care preprofessionals align to important design features of serious games?

Methods

A qualitative sample study design was employed using values and descriptive coding methodology. Values coding is appropriate for studies that seek to explore the values, beliefs, identity, and interpersonal and intrapersonal experiences of purposefully selected participants [39,40]. Semistructured interviews (Multimedia Appendix 1) were conducted with 8 12th-grade female health science students; 2, 5, and 1 of whom reported playing games as *not at all*, *not very often*, or *1 to 2 times per week*, respectively.

Sample and Participants

A purposeful sampling approach was used to identify 33 12th-grade female health science students who reported playing games as *not at all*, *not very often*, or *1 to 2 times per week*. A total of 12 young women, representing 6 racially and economically diverse northeastern US high schools, were asked to participate. Overall, 8 students volunteered to take part in the study (Table 1). These interviewees represented a diverse subset of 37 college-bound female STEM students who were dually enrolled in high school and a competitive emerging health professional (EHP) career and technical education (CTE) program. Each of these students had completed the prerequisite coursework for biology, chemistry, and trigonometry and had grade point averages of 3.0 or better. These students spent 1.5 days per week in health science–related coursework at a CTE-affiliated local state university or community college and 1 day per week shadowing health professionals at various local hospital campuses [41]. Two of these students plan to be surgeons after completing their biology/premed undergraduate degrees. Three were enrolled in 5-year accelerated physician assistant programs. One student was enrolled at a university with a guaranteed medical school track; she wants to become a pediatrician. Another student aspiring to be a pediatrician plans to complete her undergraduate degree in health policy administration before enrolling in a medical school as she wants to open her own clinic someday and needs both business and medical knowledge to do so. Finally, 1 student was still undecided regarding the type of physician she wanted to be. "I think I'll figure that out," she said, "as I'm going through my undergraduate degree" as a biology/premed major.

Written consents from both parents and students were obtained for these interviews, and the study was approved by the institutional review board of Lehigh University. The study adhered to the Consolidated Criteria for Reporting Qualitative Research guidelines [42].

Table 1. Participant profile.

Student	Race	Weekly computer time	Weekly game time	High school demographics, n (%)				Declared undergraduate major
				White	Hispanic	Black	Asian	
Harper	White	Every day	Not very often	807 (57.81)	382 (27.36)	125 (8.95)	82 (5.70)	Biology/premed
Kim	Black	Every day	Not very often	807 (57.81)	382 (27.36)	125 (8.95)	82 (5.70)	Health policy administration
Carrie	White	Every day	Not very often	2095 (79.99)	235 (8.97)	104 (3.97)	157 (5.99)	5-year physician assistant
April	White	Every day	Not very often	914 (88.91)	44 (4.28)	16 (1.56)	28 (2.72)	5-year physician assistant
Emma	White	Every day	Not very often	687 (91.97)	37 (4.95)	8 (1.07)	15 (2.01)	Biology/premed
Aria	White	Every day	Not at all	2095 (79.99)	235 (8.97)	104 (3.97)	157 (5.99)	Biology/premed
Olivia	Asian	Every day	Not at all	2308 (72.97)	379 (11.98)	94 (2.97)	316 (9.99)	Premed
Mia	White	Every day	1-2 times per week	313 (11.99)	1775 (67.98)	496 (19.00)	26 (1)	5-year physician assistant

Data Source and Procedure

Semistructured interviews were conducted with 8 students between April 1 and April 29, 2019. Twelve predetermined self-conceptualization questions were used related to the students' interests; values; and engagement in academic, athletic, extracurricular, volunteer, and leisure activities (Multimedia Appendix 1). Follow-up questions were asked based on the student's responses to the predetermined questions related to associated game design elements such as competition, collaboration, feedback, and personal win state. The duration of interviews ranged between 18 min 35 seconds and 30 min 26 seconds (mean 22 min 37 seconds). The data from transcribed audio recordings of the interviews were systematically coded using the data analysis software, NVivo Plus 12.

Data Analysis

The data analysis process was rigorous, iterative, and occurred concurrently throughout the study, starting with interview transcriptions [39,43]. Specifically, data coding occurred in 2 cycles [40]. The first cycle analysis distilled the data into core topical units using deductive and inductive values and descriptive coding as they emerged during the interviews and transcriptions [40]. New data were compared with previously coded data, with codes added, modified, and/or eliminated as data were analyzed. A blend of 45 deductive and inductive value and descriptive codes were used for the first cycle coding. A total of 14 deductive value codes were used based upon the expectancy-value motivational theory [44], the theory of expertise and expert performance [45], and the self -determination theory [46]; 21 deductive descriptive codes were based upon those used by other simulation-based learning and serious games researchers [19,25,31,32,47-53]; and 10 additional inductive descriptive codes emerged during the transcription. The codes were eliminated, modified, or recoded to fundamentally similar codes during the first cycle analysis, which resulted in 17 final codes (Table 2). The first cycle coding definitions and illustrative quotations from interviewees can be found in Multimedia Appendix 2.

The second cycle of analysis used axial coding, which synthesized the data from the first cycle coding into 4 broader, more encompassing categories. These categories were further synthesized into 2 dominant themes [40]. The student interviews, coding, and analysis were conducted by the first author. Coding in most small qualitative studies is typically a pragmatic *solitary act* [40] by a single researcher. The first author has been teaching health professionals for 38 years and is a doctoral candidate with training and interview experience in a research-intensive teaching, learning, and technology PhD program. The second author audited the coding and analysis to ensure methodological coherence.

Table 2. Deductive and inductive codes.

First cycle codes	Interviewees, n	Responses, n	Second cycle codes	Themes
Games	8	52	Return on invested time	Accomplishment
Work ethic	8	34	Return on invested time	Accomplishment
Time constraints	6	11	Return on invested time	Accomplishment
Cost value	7	34	Return on invested time	Accomplishment
Games	8	52	Achievement orientation	Accomplishment
Feedback	8	23	Achievement orientation	Accomplishment
Concrete actionable challenges	4	11	Achievement orientation	Accomplishment
Purposeful practice	6	7	Achievement orientation	Accomplishment
Competition	8	23	Achievement orientation	Accomplishment
Mastery success measures	4	10	Achievement orientation	Accomplishment
Physical fidelity	5	15	Achievement orientation	Accomplishment
Games	8	52	Social orientation	Affiliation
Family/community	8	27	Social orientation	Affiliation
Beneficence	7	22	Social orientation	Affiliation
Leadership	5	10	Social orientation	Affiliation
Games	8	52	Relevance	Affiliation
Introspection	8	34	Relevance	Affiliation
Smartest girl in the room	5	9	Relevance	Affiliation
Personally meaningful stories	8	40	Relevance	Affiliation
Confidence	4	6	Relevance	Affiliation

Results

The findings suggest that the study participants exhibit a complex fusion of desire for both *accomplishment* and *affiliation.* They consciously self-regulate their active engagement with the academic, athletic, extracurricular, volunteer, and leisure activities they value. These valued activities are compatible with present or long-term goals that are sequentially reinforced in socially relevant contexts. These findings are aligned with the self-determination theory [46], which is grounded in the assumption that students are intrinsically motivated to seek out challenges and productive activities that extend their existing capabilities. These students expressed internally regulated thinking and behaviors that prioritized their sociocognitive and affective resources based upon activities that foster autonomy, competency, and relatedness.

The findings also support those of other researchers who suggest that targeted female learners cannot be simplistically defined by serious game designers as biological females with stereotypical feminine attributes [5,15,37]. These students articulated a multifaceted mixture of commonly prescribed masculine and feminine characteristics. The masculine characteristics expressed indicated that all students were fiercely independent and competitive leaders. They embraced overcoming expected failures; thought strategically; and voiced tactical, self-regulated, time-investment behaviors to achieve personally meaningful, nonforgiving, high-stakes future win states. These female students also expressed feminine gender attributes such as empathy and compassion. Prosocial thinking, attitudes, and behaviors were articulated throughout all interviews related to interactions with peers, teachers, coaches, families, and communities. In addition, the parasocial connections that these students have with personally meaningful fictional media personas, synthesized with their mixed gender characteristics, provided a compelling depiction regarding how these students self-conceptualize their present and future selves. Ryan and Deci [46] suggest that student identification, and the need to be socially connected to important others, leads to a more self-determined and autonomous form of motivation that is centrally important for learning activities to be internalized.

Collectively, the overarching themes of *accomplishment* and *affiliation* provide evidence regarding the values, attitudes, and beliefs that contributed to the nongaming behaviors of these female emerging health care preprofessionals. Conversely, these values, attitudes, and beliefs can also be used to inform the design of a serious health science game that these students will be intrinsically motivated to play. These findings support those of Jenson and de Castell [10], Kneer et al [15], and Shaw [5,17] who suggest that a blend of self-conceptualized identity characteristics might be a better predictor of a player's choice to exert focused effort in game immersion than biological sex.

Accomplishment

The theme of *accomplishment* was synthesized through the strongly associated subthemes of *achievement orientation* and *return on invested time*. These students devote whatever time is necessary to personally relevant, difficult, practical, and highly competitive endeavors in pursuit of long-term goals while consciously avoiding what they consider to be non–goal-oriented activities, such as playing hardcore, casual, or online video games. Beyond the number 1 ranked priority of *schoolwork first*, which was expressed by all 8 students, 6 of these students play high school varsity or club sports, and 3 work between 3 and 5 days per week at part time jobs. Regardless of their perception of games as either an appealing or unappealing leisure activity, their active decision-making processes to make the most responsible return on invested time choices were readily transparent in all interviews. One unexpected finding was that the current commercial gaming activities reported by some of these young women on the demographic survey were not consistent with their gaming activities as younger children reported during the interviews. This reprioritization of playing games as a leisure activity between the ages of 18 and 24 years has been reported by others. In their study of 190 female undergraduates, Winn and Heeter [54] reported that the student's lack of available discretionary time was the primary reason for rarely or never playing games.

When she was younger, Harper played *Call of Duty* with her brother. She also used to play surgery games on her iPad all the time but does not play games very often now as she is so busy with the EHP program which "puts [me] ahead of other kids [my] age." April, Carrie, and Emma, who also reported playing games *not very often*, prefer card games now to video games. A triple jumper for her varsity track team, April, used to play *Mario Kart* with her sister when they were younger, but "then just kind of like didn't anymore. I don't know," she says, "It just kind of stopped." April likes to play a variety of card games such as *Poker* and *Spit*, "and it gets [way] too competitive," she said. The responses from Carrie and Emma were similar. Carrie reported that she used to play *Wii* when she was "little" but is no longer interested in video games. She too enjoys playing card games such as *Hand and Foot*, *Spit*, and *Golf* with family and friends during the very limited time she devotes to leisure activities. "I do try to relax or hang out with my mom or friends," Carrie said, "for at least 2 hours on a Friday or Saturday." When asked why she did not play immersive multiplayer games with her devoted gamer boyfriend, she air-mimicked fingering a controller and rolled her eyes while saying:

> *I wouldn't say there was...isn't a like a particular reason. I just feel...maybe that I would just...I don't want to spend all my time like...like watching a screen. I'd rather like get...I'd rather like go outside or something like that.*

A varsity soccer player, Emma, also works as a part time waitress 5 days a week anticipating the need for spending money in college. She has liked some video games such as *Mario Kart* in the past, but now also prefers card games such as *Uno*, "because I'm super good at it." Emma reported not playing video games "like the boys play on like the Xbox." She said, "I do not like those...I don't even like watching them." Emma described the cost-value struggle of making harder future choices saying, "Hanging out with my friends," she said, "is obviously the thing I want to do most...but it's kind of hard...when people ask me to hang out and I have to say no because I have work or have to study for an exam." Olivia, who reported not playing any video games at all, admitted to doing so on occasion if she is really bored in class. "I just like open up *Fire Boy and Water Girl*," she said, "but that's like too rare to write down that I play games." Olivia actively participates in other high-stakes competitive gaming endeavors such as varsity volleyball, where she is currently ranked 17th in conference "kills," as well as the Science Olympiads. Aria confirmed that she "never plays games—not even on my phone" as "it would take up all my time" and "it's not good for me." A varsity soccer player, Aria, also works part-time as a waitress. She also described the cost-value struggle of making present choices to achieve long-term goals saying, "it's kind of hard sometimes...like the juggling...you know...when I feel like having fun but I have to do something else...that's difficult for me...for sure." Kim, who reported playing games *not very often*, was an avid gamer when she was younger, citing games such as *Wii Athlete, Just Dance, Mario Kart,* and *Nick Junior*, which she played frequently. A varsity track record holder, Kim, said, "I just don't have time" to play games, emphasizing, "I don't even read anymore...like that says a lot." Describing her preferred leisure activity, Kim said:

> *I loved reading ever since I was little. I would [come home from] the library with like 10, 15, 20 books and I would be stuck in my room. It got to the point when my mom had to hide my books and tell me to come out because I would literally just read book after book after book and not get tired of it.*

Given her current academic and athletic priorities, Kim limits her game play to periodic, brief 15-min rounds of *Temple Run* on her phone or playing *Just Dance* or something on the *Wii* "if there's a family thing happening or kids from my church come over...but that rarely happens." Finally, Mia, who reported playing games 1 to 2 times per week, used to play games such as *SimCity* a lot but plays less now because of her busy schedule. A varsity field hockey player, Mia, works a 4-hour shift as a waitress 5 days a week to pay for car insurance, gas, and repairs, in addition to money for college. Although Mia too chooses reading as her preferred leisure activity, she still does play *SimCity* or *BitLife* to relax periodically, but concurrently admits that it "wastes my time."

All 8 students in this study expressed a bias for excellence in all academic, athletic, extracurricular, and volunteer activities, where they chose to invest their time. They reported embracing concrete actionable challenges, expected needing to overcome failure to achieve their goals, and appreciated varying degrees of feedback while practicing to improve incremental performances. The type of feedback that was considered motivational, however, was situational and varied among the students interviewed. When discussing when she played a lot of surgery games on her iPad, Harper shared that she does not like to be fed all the information needed to solve a problem, saying:

> *I like to figure it out for myself. A helpful clue here or there is nice...if you're really stuck...[but]...you have to make mistakes to learn...actually learn.*

Carrie echoed this characteristic of independently solving academic challenges herself and only goes to her teacher for helpful suggestions if stuck. April described herself as a visual learner who needed more specific feedback using an example of how watching videotapes helped improve her long jump performance. April's coach used the videotapes to show her what she was doing wrong. "This helped me," she said to see "what I look like" compared with "what it should look like" so "then I can fix it." Conversely, Olivia sometimes likes feedback that is a bit more intense. "I like when people yell at me," Olivia said. "I improved [in Volleyball] the most my sophomore year," with a more clamorous coach, she said. "We would stand on these boxes and then I'd be hitting and [my coach] would be yelling...like harder...come on...harder...hit to this spot...and [if] I missed she'd be like...come on...why did you miss it?" Similarly, Kim expressed a need for more demanding feedback. "My coach," said Kim:

> *he always pushed me...and I could take that from him. He would push me...and I'd say, 'Coach, I can't', and he's like, 'listen, you're fine.'*

This type of tough, unforgiving feedback was intimidating for Aria and Emma who stated a preference for a softer, more encouraging approach. "We always played better [soccer]," Aria said, "with the assistant coach who let us have fun…but at the same time...like showed you how to be like the best player you can be." Emma echoed these feelings saying, "I like someone who's able to like tell me what to do...and like respects me as well." Mia described a balance, expressing that the degree of feedback needs to be commensurate with performance expectations. "Our [Field Hockey] coach didn't really discipline us," she said. "I thought that if she did, we would have been better in shape...and our season probably would have turned out a lot better if there was more discipline." The team, she said, "just joked around...we weren't really serious about it anymore." In addition, Mia imagined that "we would have respected [the coach] a little bit more" had there been more disciple.

Affiliation

The overarching theme of *affiliation* was synthesized through the strongly associated subthemes of *relevance* and *social orientation*. All 8 young women expressed important relationships with others when describing their academic, athletic, extracurricular, and leisure activities. Their thinking and attitudes about relatedness clearly shaped how these students conceptualized their present and projected future selves. The students' identification with others was influenced by real-world peers, family members, coaches, and mentors. All 8 students valued relevant and personally meaningful shadowing experiences with health professionals at various local area hospital campuses, which validated or helped to reconstruct their future aspirational selves [55]. Five of these students chose to invest their limited leisure time in empathetic prosocial volunteer activities, and 4 were in academic and/or voluntary leadership positions. These students did not perceive themselves to be unimportant or powerless in these roles and often emerged as active, confident leaders who achieved meaningful results. All 8 students who responded that they played games or participated in athletic activities as a leisure activity in the past or present almost always associated it with a meaningful connection to others.

Affective parasocial connections with favorite fictional characters also appear to have contributed to the students' self-conceptualization [56]. Lucas and Sherry [3] argue that choice in media consumption to meet individual gratification is one possible source of influence in determining future choices. Shaw [5] supports this idea and has suggested that the totality of media consumption across TV, films, books, and music might offer unique insights into an individual's self-conceptualization that can help inform designers to predict potential individual gameplay preferences. Chen et al [38] also urge designers to consider more nuanced audience analysis questions about the specific affective experiences of students as they participate in broader media consumption because girls are typically less drawn toward computer games than boys but do not show differences in their interests for movies. Relevant and personally meaningful fictional characters for this study cohort included 8 female, 2 male, and 1 animated persona. These characters were decidedly different than the hypersexualized females, damsels in distress, or stereotypical beauties that have been described in digital hardcore and casual game research to date such as Laura Croft (*Tomb Raider*), Daphne (*Dragon's Lair*), and Kim Kardashian (*Kim Kardashian: Hollywood*). This finding, in addition to the cited, more gender-neutral, digital games played by these students, suggests that there was no alignment for these health science–oriented students to take on a compatible role of player in such games [16,30,56]. Conversely, the students' identification with their favorite fictional characters, and their stories, was often aligned with descriptions of their cognitive, social, and affective real-world choices and relationships.

April, who is enrolled in an accelerated 5-year physician assistant program after graduation, credits a babysitter who spoke about her EHP experiences for initiating her interest in the medical field. "When I came into this [EHP program]," April said:

> *I was thinking that I wanted to work in the emergency room as a physician's assistant, but I've had the opportunity to shadow...in the Neonatal Intensive Care Unit and Pediatric Intensive Care Units...so now I'm thinking maybe I'll go that way or even the pediatric ER.*

She identified her favorite fictional character as Hermione Granger, the overachieving muggle-born witch in the Harry Potter novels, who excels academically. Hermione is someone who does "whatever she wants to do," April said:

> *[not] what everybody expects her to do. She's kind of like making her own like path...at the end she's like taking like three classes at a time and she's popping from like class to class because that's what she needs to do. She's always like super smart like figuring out how to do everything and thinking on her feet...and*

> *she's like sort of a leader but not always like the leader.*

Her description of a super smart Hermione Granger, who is just doing what she needs to do to be successful, may help validate April's self-conceptualization and her prioritization of the unpopular, harder classes that she cares about the most, such as advanced placement chemistry and calculus. After a 5-year commitment as a counselor working at a summer camp for kids with special needs, April recently joined the junior board of directors for Camelot for Children to help increase donations. April likes playing card games with her family when she has time.

Sixteen-year-old Starr Carter, an economically disadvantaged black girl who attends an elite, primarily white boarding school in the book *The Hate U Give*, was Kim's favorite fictional character. After witnessing a police officer shoot and kill her unarmed best friend, Starr Carter must overcome her trauma and those who seek to disempower her in her divergent socioeconomic and political realities. Kim, also a minority student, is immersed in 2 very different socioeconomic academic settings. A black female who demographically represents just 8.95% (125/1396) of her economically disadvantaged high school and 3% (2/58) of her predominantly white EHP class, Kim, admired Starr Carter's courageous transformation into an advocate for truth and justice. She explained that her interest in medicine was influenced by her certified nurse assistant parents who challenged her to be a physician instead of the nurse practitioner she initially aspired to be. Kim, who had decided to become a pediatrician someday because of her squeamishness around blood, was animated as she explained how her enduring self-perception had been proven false when she observed an open-heart surgical procedure. "I was right next to the surgeons," she said.

> *They let me come forward and see everything. I saw the entire surgery...I wasn't squeamish...like...I was just fine.*

Kim will soon represent the first generation of her family to attend college, and her undergraduate trajectory is unique. Unlike her EHP peers, Kim plans to earn her degree in health policy administration so that she understands the business aspects of running her own clinic before enrolling in medical school to become a pediatrician. When Kim spoke about varsity track, she never mentioned her record-breaking accomplishments but richly described her role as a leader within her athletic family. "When I was a freshman," she said:

> *we had these two athletes...they were boyfriend and girlfriend...we called them mom and dad...they were the ones who took us in. But now that I'm the senior...like I'm taking everybody in...Like I'm taking everybody under my wing. I'm always there for them and they're always there for me.*

Kim, who described herself as a digital "gamer" when she was younger, rarely plays games now because of her academic and athletic priorities. When she does play, it is usually with family or friends.

Aria's favorite character was Deborah Dobkins from the TV show *Drop Dead Diva*. A vapid aspiring model, Deborah's shallow soul is brought back to life in the body of Jane Bingum, who was a brilliant, hard-working, charitable, plus-size lawyer. Deborah Dobkins is "not very smart," Aria said.

> *Like...not saying that models aren't very smart...but she wasn't very smart...but she walks into the courtroom with like so much confidence and she just wins every time. And it's so crazy to me...like knowing that she's not qualified...but she can just do it.*

Interestingly, Aria addressed being similarly conflicted, sometimes feeling like 2 personas in 1 body, continuously choosing between the roles of serious, responsible student and just wanting to have fun and hang out with friends. As a freshman, Aria had a good friend in the EHP program who just loved what she was doing. "She told me a lot about the program...and I was like...that sounds amazing...like that's what I want to do," Aria said. Since those initial conversations, "there's never been like a question for me...like saying that I want to go into the medical field." Aria continued, "like it's the only thing I can see myself doing." Aria will begin her undergraduate studies as a biology/premed major after she graduates high school, aiming to pursue medical school someday. Aria described herself as "a pretty busy gal...in like a ridiculous amount of clubs," but she values being involved in her school. As the secretary of the Pediatric Cancer Club, she recently led a *Shave for the Brave* event that raised over US $100,000 for pediatric cancer patients. Aria also mentors newly enrolled students at her high school to help ease their transition. Aria confirmed during the interview that she does not play games as it would not be a good use of her time.

A white female who demographically represents just 11.99% (313/2611) of her economically disadvantaged high school, Mia, has been accepted into an accelerated 5-year physician assistant program. She explained that she began "wanting to find her spot in the healthcare field" as she had a good friend who was diagnosed with leukemia when they were very young, and the people who cared for him motivated her interest. Mia's favorite fictional character was Thomas Edison, the amnesic protagonist in the novel *Maze Runner*, who transforms himself from a scared, confused adolescent to a courageous, decisive leader in a dangerous apocalyptic world. "I like how he just like took over everything," Mia said. "He was different than the others [in the maze]...he wanted to lead them to safety and no one else did...they didn't want to go...they didn't want to do anything." Mia may identify with Thomas' initiative to escape his maze as she too is different academically and planning to escape her own low-achieving high school "maze," which is ranked 516 of 673 schools in the state, with math proficiency and reading proficiency scores of 32% and 43%, respectively. When one considers Mia's feelings regarding her new CTE peer group compared with the demographic environment of her high school, her identification with Thomas seems even more salient. "I've created a better relationship with my friends here," Mia said. "All the kids here are interested in the medical field...I had people that related to me...and understood what I was going through...like picking colleges." Mia was the most frequent game player of this group of students, who reported playing

SimCity “all the time” when she was young and still plays 1 to 2 times per week when she is bored or needs time to relax. In the *SimCity* games, players build their own societal stories to fit their own desired cultural contexts [1,5,16]. Given Mia’s low achievement and economically disadvantaged high school environment, her description of the *SimCity* character she created is noteworthy. “Right now, my girl...I made her,” Mia said. “She lives in the city...and I took her to college for a business degree...and then she spent like three weeks there... and now she’s in Paris on vacation.” As the president of Key Club, Mia increased the annual benevolent Key Club projects by over 400% by adding community food drives and monthly parent-teacher association meeting babysitting services. When Mia entered the EHP program, she wanted to be a pediatrician but decided against becoming a doctor while shadowing them because of conflicting lifestyle choices. Mia did not like seeing physicians who were content working while their families were on vacation. “That wasn’t me...that was not me at all,” she said. “I want to have a life. I want to travel and have a family.”

Discussion

A more nuanced analysis of prospective female players has been advocated before the design and development of serious games. This study sought to better understand the values, attitudes, and beliefs that contributed to the nongaming behaviors of 8 12th-grade female emerging health care preprofessionals. It was anticipated that these understandings would help inform the design of a serious game that these students might be intrinsically motivated to play.

Principal Findings

The findings of this study suggest that these 12th-grade health science–oriented students exhibit a complex fusion of desire for both *accomplishment* and *affiliation* representing a multifaceted mixture of commonly prescribed masculine and feminine characteristics. These young women are all are fiercely independent, introspectively competitive, prosocial leaders who are intrinsically driven to pursue health care careers. They think strategically and have tactically structured their past and present lives to achieve personally meaningful long-term goals. They embrace overcoming expected failures to achieve relevant high-stakes wins in all academic, athletic, extracurricular, and volunteer activities they value. They consciously avoid what they consider to be non–goal-oriented activities and subsequently self-limit their leisure time. When investing constrained leisure time, they choose to do so in socially meaningful contexts, which may include rarely playing games. On the basis of these common student attributes, the following design elements are recommended to foster autonomy, competency, and relatedness when seeking to motivate nongaming female students to independently choose to persistently play a health science–related serious game to mastery.

Implications for the Design of Serious Games

With regard to the theme of *affiliation*, it is expected that these preprofessional health care students will be more motivated to engage in a serious game that contains a relevant story [47,57]. Emotionally placing these students in a game environment with near real-world patient characters should trigger their feelings of empathy and compassion. Engagement with such characters in a meaningful and emotionally rich story may lead female health science students to identify with patient personas resulting in inherent prosocial behaviors and feelings of responsibility and accountability [12-30]. These relevant stories should unfold in an authentic clinical practice environment, which combines near real-world social interactivity and authentic behavioral dynamics and likely workflow distractions [19,32,48,51]. It has been suggested that eliciting emotional arousal in learners may result in the student’s self-regulation and motivation for achievement [58-60]. It is expected that well-designed emotional triggers provided by nonplayer patient characters in authentic clinical environments will align with the existing values, attitudes, and beliefs of female health science students. The resulting interactive parasocial relationship between these students and nonplayer patient characters should impact the active choices these students make to persist to achieve in the face of whatever concrete actionable challenges they face in the game.

With regard to the theme of *accomplishment*, authentic, concrete, actionable challenges should be designed into the serious game, which improve the fictional patient’s clinical status while protecting them from harm [19,32,51]. It is expected that female health science students who identify with nonplayer patient characters will embrace solving their clinical problems by learning to use, manipulate, and reconfigure applicable tools while navigating visually rich authentic clinical environments [8]. Increasingly difficult levels of incremental knowledge, skills, attitudes, or behaviors should be achieved through repetitive, increasingly difficult practice until the students reach an individually meaningful win state in which their fictional patient’s clinical issues are resolved without any adverse events [19,32,47,51]. The serious gaming environment should provide these students with nonforgiving, high-stakes feedback in the form of performance-based rewards and performance-based penalties, which are aligned with incremental successful or unsuccessful fictional patient care based upon knowledge, skills, attitudinal, or behavioral benchmarks that are clearly defined and measured [19,25,32,47,49,51]. Finally, the design of instruction should allow each student to decide how he or she chooses to respond to likely workflow distractions, or time constraints, to achieve success at each instructional level [8,19,32,49,51].

Limitations

The participants in this study represented 18.6% of the total female EHP student population and 21.6% of the original study cohort in prior research reported by the authors [9] and reflect a small sample size. The themes that emerged in this study may not reflect those of the collective group of college-bound health science learners in this class or those of incoming classes.

Conclusions

The results of this study reinforce the need for a robust learner analysis to identify the multifaceted behavioral characteristics of targeted learners before the design and development of serious games. The common characteristics of the 12th-grade female health science students in this study indicate that they will choose to invest their limited leisure time playing a serious game if it is aligned with the self-conceptualization of their present or future selves. It is expected that these students will choose to solve sequentially difficult concrete, actionable, patient care challenges if they parasocially identify with the nonplayer patient characters in a relevant story that takes place in an authentic clinical practice environment with authentic behavioral dynamics and likely workflow distractions. It is expected that female health science students will choose to persist to an individually meaningful win state on behalf of their nonplayer patient characters as they receive formative feedback in the form of performance-based rewards and performance-based penalties, which are aligned with incremental successful or unsuccessful procedural care.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Semistructured interview guide to better understand the motivational dynamics of why 12th-grade emerging health professional students might choose to play games.

[PDF File (Adobe PDF File), 435 KB - games_v8i1e16003_app1.pdf]

Multimedia Appendix 2

First cycle coding definitions and illustrative quotations from interviewees.

[PDF File (Adobe PDF File), 490 KB - games_v8i1e16003_app2.pdf]

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Abbreviations

CTE: career and technical education
EHP: emerging health professional
STEM: science, technology, engineering, and mathematics
TV: television

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Review

Health Education Serious Games Targeting Health Care Providers, Patients, and Public Health Users: Scoping Review

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Abstract

Background: Serious educational games have shown effectiveness in improving various health outcomes. Previous reviews of health education games have focused on specific diseases, certain medical subjects, fixed target groups, or limited outcomes of interest. Given the recent surge in health game studies, a scoping review of health education games is needed to provide an updated overview of various aspects of such serious games.

Objective: This study aimed to conduct a scoping review of the design and evaluation of serious educational games for health targeting health care providers, patients, and public (health) users.

Methods: We identified 2313 studies using a unique combination of keywords in the PubMed and ScienceDirect databases. A total of 161 studies were included in this review after removing duplicates (n=55) and excluding studies not meeting our inclusion criteria (1917 based on title and abstract and 180 after reviewing the full text). The results were stratified based on games targeting health care providers, patients, and public users.

Results: Most health education games were developed and evaluated in America (82/161, 50.9%) and Europe (64/161, 39.8%), with a considerable number of studies published after 2012. We discovered 58.4% (94/161) of studies aiming to improve knowledge learning and 41.6% (67/161) to enhance skill development. The studies targeted various categories of end users: health care providers (42/161, 26.1%), patients (38/161, 23.6%), public users (75/161, 46.6%), and a mix of users (6/161, 3.7%). Among games targeting patients, only 13% (6/44) targeted a specific disease, whereas a growing majority targeted lifestyle behaviors, social interactions, cognition, and generic health issues (eg, safety and nutrition). Among 101 studies reporting gameplay specifications, the most common gameplay duration was 30 to 45 min. Of the 61 studies reporting game repetition, only 14% (9/61) of the games allowed the users to play the game with unlimited repetitions. From 32 studies that measured follow-up duration after the game intervention, only 1 study reported a 2-year postintervention follow-up. More than 57.7% (93/161) of the games did not have a multidisciplinary team to design, develop, or assess the game.

Conclusions: Serious games are increasingly used for health education targeting a variety of end users. This study offers an updated scoping review of the studies assessing the value of serious games in improving health education. The results showed a promising trend in diversifying the application of health education games that go beyond a specific medical condition. However, our findings indicate the need for health education game development and adoption in developing countries and the need to focus on multidisciplinary teamwork in designing effective health education games. Furthermore, future health games should expand the duration and repetition of games and increase the length of the follow-up assessments to provide evidence on long-term effectiveness.

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KEYWORDS
serious games; health education; health games; game-based learning

Introduction

Background

Serious games have emerged as a promising educational technique across various domains [1,2]. Previous studies, including a survey study, have identified health care as one of the main targets of educational serious games [3-5]. In contrast to traditional educational techniques, the focus of serious games on health is partly derived from the fact that they provide individuals with a risk-free environment to practice high-stake tasks and experience unpredictable outcomes. Serious games also provided a unique educational platform to increase patient safety and reduce cost, which, in turn, has propelled the rapid development of new health education games [6,7].

User acceptance is key to the successful impact of educational serious games. Previous studies have assessed various user acceptance challenges of educational games [8,9]. These studies revealed that a wide range of users, including health care providers and medical students, accept serious games as a substantial and useful educational technique [10,11]. These studies also showed that clinical instructors consider serious games as an attractive and engaging educational tool [8,12]. Higher engagement is partly explained by the active learning tasks experienced by the users while interacting with an educational game [13,14].

Similar to other educational techniques, serious games require goal-relevant design, and their effectiveness should be methodologically evaluated [15]. Designing educational serious games requires multiple stages to ensure the engagement of potential end users in all phases of development, ranging from flowcharts and wireframes to multidimensional design and repeated user experience tests [16]. In addition, to increase the generalizability of educational serious games in improving learning objectives, they need to be rigorously evaluated across different user groups using various methods ranging from user studies to focus groups and clinical trials [17].

Several review studies have evaluated the design, development, and outcomes of serious games; however, only a few have focused on health education games [7,15,16]. One study conducted a systematic review of educational serious games for medical students and concluded that serious games should be evaluated before use in medical school curricula [17]. Another study conducted a meta-analysis of sex education serious games and concluded that serious games can be used effectively for promoting sexual health [18]. Moreover, another study evaluated the frequency and progression of health serious games across various domains, including clinical training, rehabilitation, and health education [5]. Considering the current rapid development of serious games, an updated scoping review focusing on health education serious games is lacking.

Study Objectives

This study offers an updated scoping review of health education games. The study reviews various aspects of the recent developments of educational health games designed for various user groups and provides a comprehensive review of the design characteristics and evaluation of such serious games. The study also addresses the gaps and weaknesses of the recent developments of health education games.

Methods

Overall Framework

The York framework was used to develop the general framework of this study [19]. We followed the following stages to guide the methodology of our search and analysis: (1) identifying the research question; (2) identifying relevant studies; (3) search strategy and study selection; (4) extracting information from the studies; and (5) collating, summarizing, and reporting the results.

Research Questions

Systematic reviews often focus on specific questions; however, scoping reviews explore questions with a broader scope [20]. In this review, the overarching aims targeted 3 *aspects* of health education serious games: general information, design specifications, and evaluation outcomes. Specific questions targeting each aspect of these health education games were discussed by a group of medical informatics experts (2 faculty members and 4 graduate students) and selected through a consensus process (Table 1).

Table 1. Study questions and corresponding health game aspects.

Game aspects	Specific questions
General	• What is the frequency of publications per year? • How articles are allocated geographically? • What are the overall goals of the study?
Design	• What are the characteristics of the target groups? • What are the types of educational content offered by the games? • What types of medical conditions were targeted? • What is the distribution of gameplay duration across the studies?
Evaluation	• How many repetitions were made in the studies? • What was the intervention duration in the studies? • What was the duration between the intervention and posttest? • What follow-up period was used to evaluate the games? • What were the findings of the studies?

Identifying Relevant Studies

The research team used an established framework [20] to develop an overall guideline used to identify if a study is considered relevant to the topic of the scoping review. The guide specified additional details about the articles on 3 perspectives of population, concept, and context (Table 2). The research team then applied this guide to develop a detailed inclusion and exclusion criteria for the review process.

Table 2. Overall guideline for the inclusion and exclusion of articles.

Items	Description
Population	The search strategy should not limit the educational groups targeted by the studies *(eg, no limitations in terms of gender, age, health, or economic status)*
Concept	The search strategy will not discriminate about the underlying educational goal of the games and will be agnostic about the platform used to deliver the games *(eg, no limitations on the learning techniques and no limits on software choices)*
Context	The search strategy will not limit the inclusion based on the affiliation of authors but will limit the papers to English articles published between January 1985[a] and December 2018

[a]Previous systematic reviews identified no health education game studies published before 1985.

Search and Screening Strategy

The search strategy was guided by the overall inclusion and exclusion framework (Table 2). After reviewing a handful of serious games articles, including review articles, and consulting informatics professionals, the study team developed a set of *potential* keywords to match the overall inclusion and exclusion criteria of the articles (Table 3). To accommodate a wider scope of articles, 3 sets of *potential* keywords were developed to cover gaming, health, and education domains and later were assessed for comprehensiveness while being converted into a unified and single keyword phrase.

Table 3. Concepts and potential keywords.

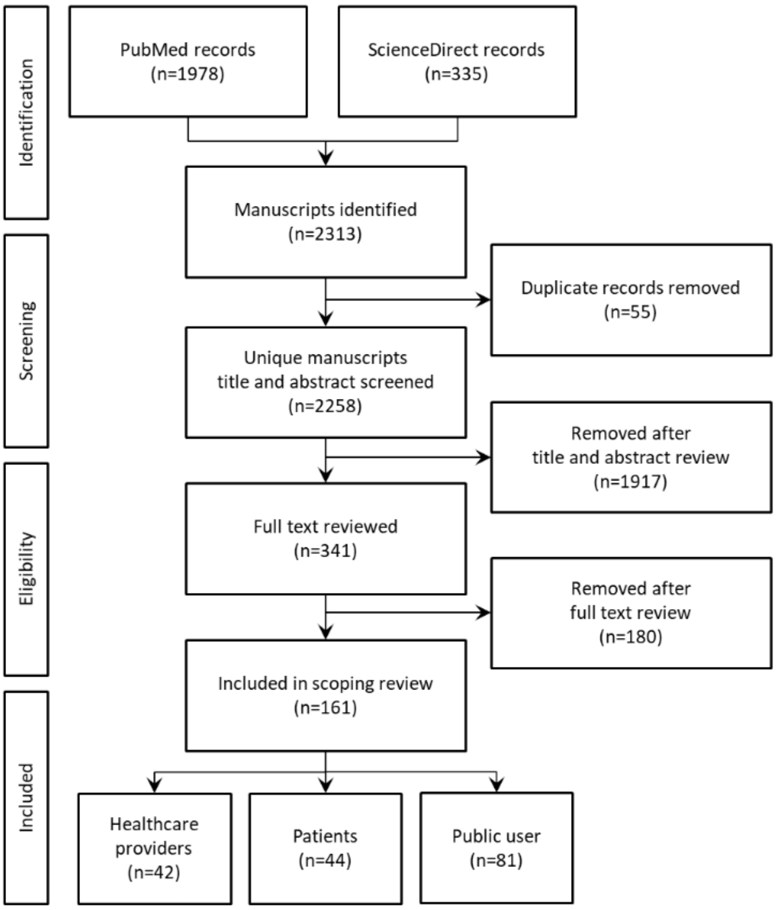
Concepts	Keywords[a]
Game	Game OR (Video Game) OR (Serious Game) OR Gamification OR Gaming OR (Computer-Aided Design) OR (Computer Simulation) OR (Computer Graphics)
Health	Health OR Medicine OR Medical
Education	Education OR Teaching OR Learning OR Training OR Problem-Based Learning OR Computer User Training OR Simulation Training

[a]On the basis of determined keywords and concepts, the search team developed and used the following composite keyword to search for the studies of interest: *((video game) OR (videogame*) OR (serious gam*) OR (gaming) OR (gamification)) AND ((educate*) OR (train*) OR (teach*) OR (learn*)).* The publication year of articles was limited from 1985 to 2018, and non-English articles were excluded. Only original studies published in a peer-reviewed venue were included. PubMed and ScienceDirect databases were used to perform the search.

Study Selection and Inclusion

As depicted in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram in Figure 1 [21], the initial search retrieved 2313 articles from PubMed (n=1978) and ScienceDirect (n=335). After removing duplicates (n=55), 2258 articles were retained for screening. The search team used the inclusion and exclusion guidelines (Table 2) to filter the articles. Screening the title and abstract of the articles resulted in the exclusion of 1917 articles. To harmonize the results and exclude *exercise games*, health games using hardware accessories (eg, sensors) or adopting commercial games that are specifically designed for exercise (with minimal educational content) were removed during the title and abstract screening. The remaining 341 articles were furthered screened after reading their full text, which resulted in 180 articles being excluded from the study. We specifically excluded studies assessing the negative aspects of violent games, as they are not considered health games. The risk of bias was not assessed, as this scoping review did not intend to systematically review and evaluate all effective interventions. In the end, 161 articles were determined to meet all inclusion and exclusion criteria and were fully reviewed in the data extraction phase (which further split the studies based on their target groups of health care providers, patients, and public users).

Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram of the search methodology.



Data Extraction

A data extraction form was developed by the research team after the determination of the conforming variables with the research questions and the study's goal (Table 4). The variables were categorized based on the study's 3 major aspects (ie, general information, design, and evaluation; Table 1). The data extraction form was shared with all study team members and was finalized after addressing all remaining questions and comments.

In total, 2 reviewers used the data extraction form to independently mine 9.9% (16/161) of the articles. The kappa coefficient score between the 2 reviewers was calculated at 76%. Both reviewers further discussed discrepancies internally and were trained once more to reach a high consensus rate (ie, reaching a kappa score >90% in the second round of coding). Two reviewers then extracted data from the rest of the articles. In the case of nonconformation between the reviewers, a third reviewer was consulted to reach consensus.

Table 4. Data extraction form.

Game aspects	Data element to extract
General	• Country • Year
Design	• Target group • Type of study • Duration of game • Goal of game • Goal of study • Result of study • Specialty of the design team
Evaluation	• Intervention evaluation’s tool • Game evaluation’s tool • Intervention evaluation • Game evaluation • Follow-up duration • Intervention duration • The duration between intervention and test

Data Collation and Analysis

Data extraction results were collected in 2 Microsoft Excel sheets managed by each of the reviewers. The Excel sheets were then merged to generate the final set of results. Excel functions were used to populate the summary statistics and perform a frequency analysis. To analyze the captured data, we applied a frequency analysis for all variables of interest and presented the results in various chart formats. To improve the interpretability of the results, we stratified all findings into the 3 user groups of health care providers, patients, and public users.

Results

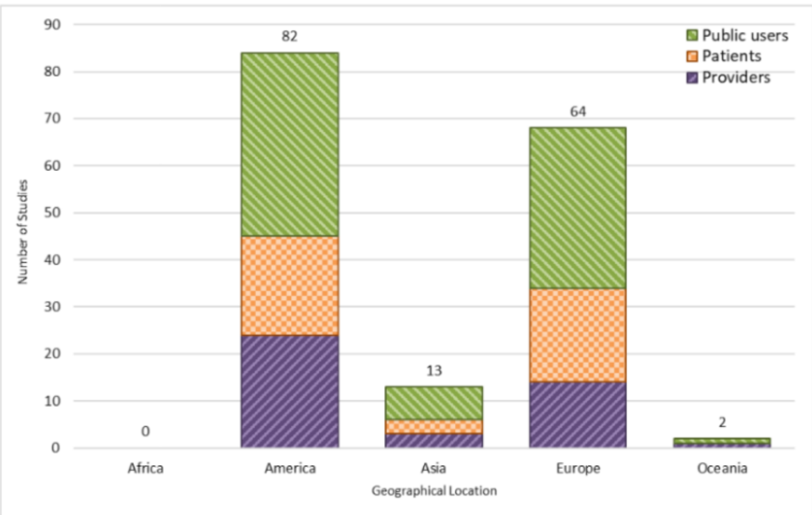
Overall Findings

The findings of this review were categorized based on health education serious game aspects and specific questions identified earlier in the review (Table 1). Significant study findings were grouped into the geographic distribution of the studies, publication year, type and goal of the studies, target groups, gameplay duration and repetitions, intervention specs, length of the follow-up period, and the use of multidisciplinary teams.

Publication by Geography

Figure 2 depicts the geographical distribution (categorized by continent) of published health education serious game articles. Most of the published articles (n=82) originated from institutions in the American continent (≥90% in North America). After America, Europe (n=64), Asia (n=13), and Oceania (n=2) had the highest number of studies assessing health education games. None of the articles were published by an author affiliated with an institution in Africa.

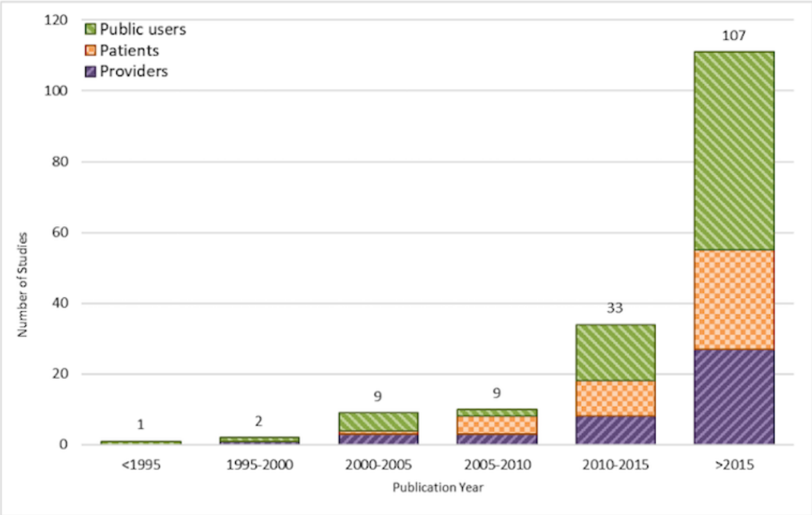
Figure 2. Studies based on geographical locations and stratified by user groups.



Publication by Year

Figure 3 demonstrated the number of articles on health education games per 5-year intervals. The first article was published in 1989. Since 2011, the number of articles has grown considerably, with a notable peak in articles published after 2015 (n=107).

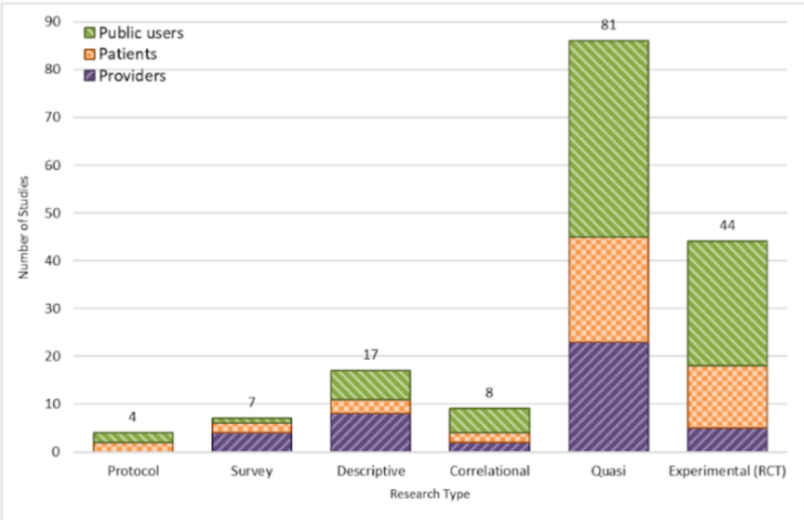
Figure 3. Studies by year and stratified by user groups.



Type of Study

In this review, articles were categorized into 2 classes of interventional (77.6%) and observational (22.4%) studies. Among the interventional studies, 44 were randomized clinical trials, whereas 81 of the studies were quasi-experimental (Figure 4). A few studies have assessed the educational health games using a qualitative approach (eg, design protocols and surveys).

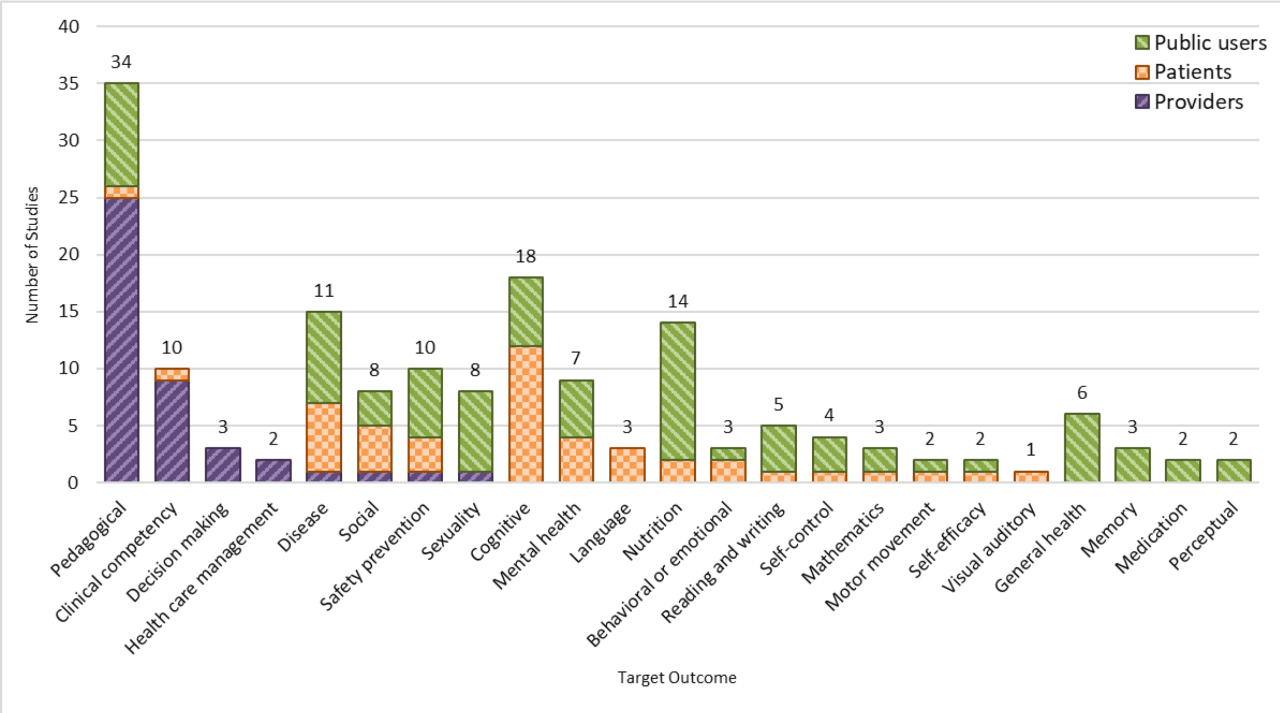
Figure 4. Publications by study design and stratified by user groups. RCT: randomized controlled trial.



Study Outcomes

Studies were categorized into 2 classes of knowledge improvement (94/161, 58.4%) and skill improvement (67/161, 41.6%). The knowledge improvement category included multiple subcategories, such as knowledge of diseases (6.8%), general health (6/161, 3.7%), health care management (1.9%), medications (1.2%), mental health (4.3%), nutrition (8.7%), pedagogical content (eg, higher education curriculum; 21.1%), safety and prevention (6.2%), and sexuality (5.0%; Figure 5). The skill improvement category also included multiple subcategories of skills: behavioral and emotional (1.9%), clinical competency (6.2%), cognition (11.2%), decision making (1.9%), language (1.9%), mathematics (1.9%), memory (1.9%), motor movement (1.2%), perceptual (1.2%), reading writing (3.1%), self-control (2.5%), self-efficacy (1.2%), social (5.0%), and visual-auditory (0.6%). Games designed for health care providers were mainly targeting pedagogical knowledge, clinical competencies, and decision-making skills. Games designed for the patients mostly focused on cognition, specific diseases, mental health, social challenges, and a growing number of specific skill sets (eg, self-control and language). Games targeting public users covered a variety of topics, such as nutrition, safety and prevention, and general health items (Figure 5).

Figure 5. Studies by target outcome and stratified by user groups.



Target User Groups

We studied 3 specifications of the target groups: age groups, user groups (eg, health care provider, patients, and public users), and medical condition (specific to patients).

Age Groups

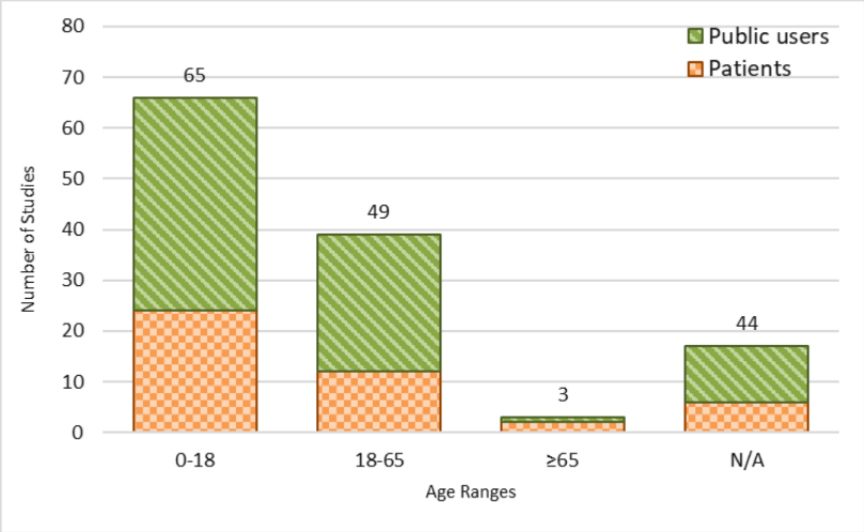
We used educational age ranges [22] to analyze age groups (Table 5). Some studies only included one of the age categories (78/161, 48.4%), whereas some included more than 1 age category (39/161, 24.2%). Approximately 27.3% (44/161) of studies did not specify the age groups. The studies that were limited to 1 age category included children (36/78, 46%), adolescents (10/78, 12%), adults (29/78, 37%), and elders (3/78, 3%) but did not include neonates or infants or toddlers target groups. Among studies that targeted more than 1 age category (39/161, 24.2%) of the articles, age categories included neonates and infants and toddlers (1/39, 2%), toddlers and children (1/39, 2%), children and adolescents (17/39, 43%), children and adolescents and adults (3/39, 7%), children and adults (1/39, 2%), adolescents and adults (5/39, 12%), adolescents and adults and elders (1/39, 2%), and adults and elders (10/39, 25%). There were no studies to evaluate neonate, infant, and toddler target groups independently.

Table 5. Age-specific considerations in patient care and health education.

Groups	Age ranges
Neonates	1 day to 28 days
Infants	29 days to 2 years
Toddlers	1 years to 3 years
Children	3 years to 12 years
Adolescents	13 years to 18 years
Adults	19 years to 65 years
Elders	≥65 years

After combining the age groups into larger age bins for games targeting patients and public users, the age bin of 0 to 18 years showed the highest number of studies (n=65), compared with 18 to 65 years (n=49) and 65 years and older (n=3, Figure 6). Logically, all games designed for health care providers fell within the age range of 18 to 65 years (not shown in the figure).

Figure 6. Studies by age ranges of health games designed for patients and public users. Educational health games designed for healthcare providers are not shown (n=42). N/A: not applicable.



User Groups

Overall, the user groups were divided into 3 general categories (Figure 1): (1) health care providers, such as physicians and nurses (42/161, 26.1%), (2) patients (38/161, 23.6%), and (3) public users (75/161, 46.6%). A total of 6 studies (6/161, 3.7%) included both patients and public users.

Medical Conditions

Of all reviewed studies, 42 (42/161, 26.1%) studies targeted various medical conditions (Table 6). These conditions were either meant to improve individual health outcomes or prevent specific diseases.

Table 6. Targeted medical conditions among different age groups of patients and public users.

Medical conditions	Age group[a] (years)								
	0-12	0-18	0-40	0-65	13-40	13-65	19-65	19-75	≥65
Addiction	—[b]	—	—	—	1	1	—	—	—
Attention-deficit/hyperactivity disorder	2	—	—	—	—	—	—	—	—
Amblyopia	1	—	—	—	—	—	—	—	—
Aphasia	—	—	—	—	—	—	—	1	—
Autism	2	3	1	—	—	—	—	—	—
Behavioral problems	—	1	—	—	—	—	2	—	—
Blood clots	—	—	—	—	—	—	—	1	—
Cancer	—	—	—	—	—	—	1	—	—
Daytime wetting	—	1	—	—	—	—	—	—	—
Dementia	—	—	—	—	—	—	—	—	1
Diabetes	—	1	—	—	—	—	—	—	—
Disabled	—	—	—	1	—	—	—	—	—
Dyslexia	1	—	—	—	—	—	—	—	—
Extremely low birth weight	1	—	—	—	—	—	—	—	—
Fetal alcohol spectrum disorders	3	—	—	—	—	—	—	—	—
HIV	1	—	—	—	—	—	—	—	—
Language disorders	—	1	—	—	—	—	—	—	—
Mathematical skills	1	1	—	—	—	—	—	—	—
Neurodevelopmental disorders	—	1	—	—	—	—	—	—	—
Overweight	—	—	—	—	—	—	2	—	—
Pain after surgery	—	—	—	—	—	—	1	—	—
Psychological disorders	1	1	—	—	—	—	—	—	—
Schizophrenia	—	—	—	—	—	1	—	—	—
Specific language impairment	1	—	—	—	—	—	—	—	—
Stroke	—	—	—	—	—	—	2	—	1
Tinnitus	—	—	—	—	—	—	—	1	—

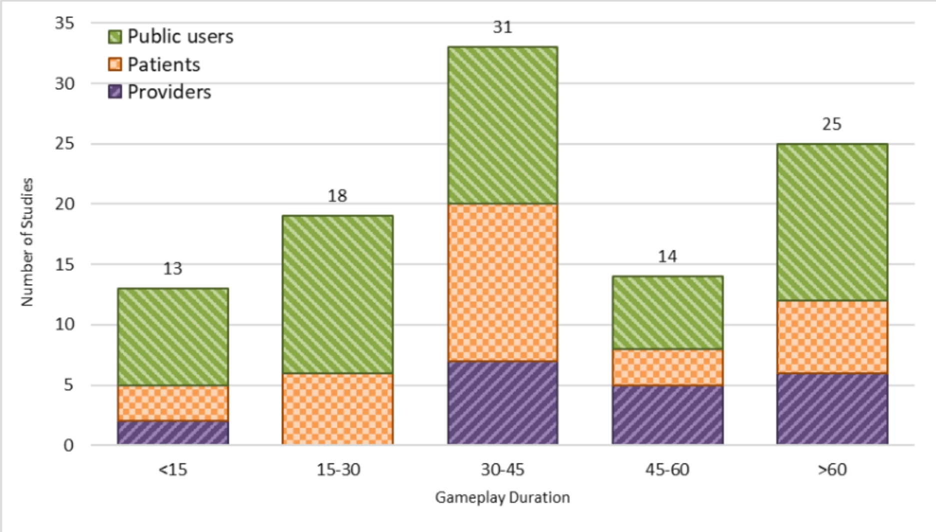
[a]Age groups cannot be combined, as studies did not report enough details.

[b]Not applicable

Duration of Gameplay

Duration of gameplay (ie, time spent on interacting with the game) has been reported in 101 studies (101/161, 62.7%). Figure 7 depicts the distribution of gameplay duration among these 101 studies. The most common gameplay duration was 30 to 45 min (n=31) and the least was less than 15 min (n=13).

Figure 7. Duration of gameplay in minutes and stratified by user groups. Studies with missing duration of gameplay are not shown (n=60).

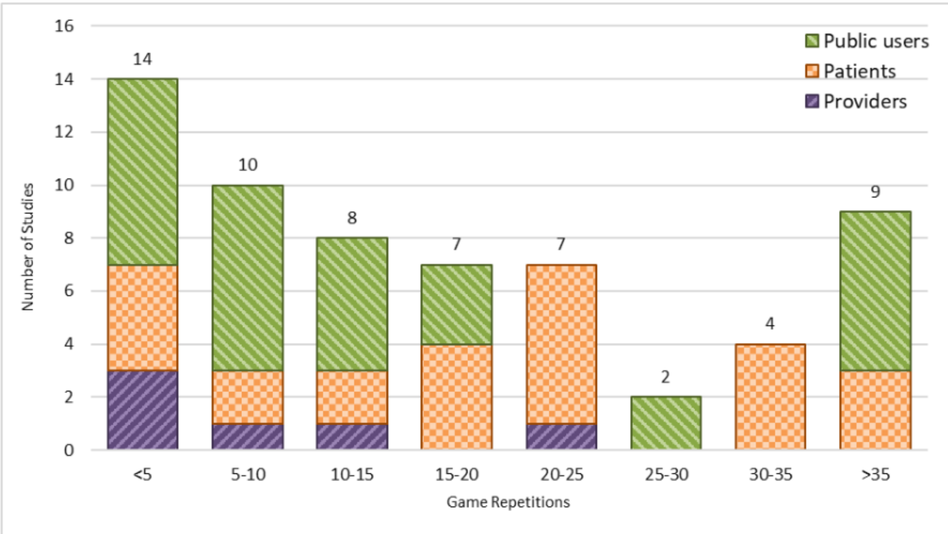


Number of Game Repetitions

Of all 161 studies, 61 health games (37.9%) mentioned the number of times the game can be repeatedly played (Figure 8). Among these studies, 2 general categories of repetitiveness were observed: (1) articles that limited the number of times a game can be played (n=58) and (2) articles that set no limitations for the number of repeats and users were allowed to have an interaction with the game with unlimited repetitions during the intervention time (n=3; a subset of >35 bar in Figure 8).

Among the articles of the first category, games with less than 5 repetitions had the highest number of articles among health care provider and public user groups. Games designed for patients had 20 to 25 as the highest number of repetitions (Figure 8).

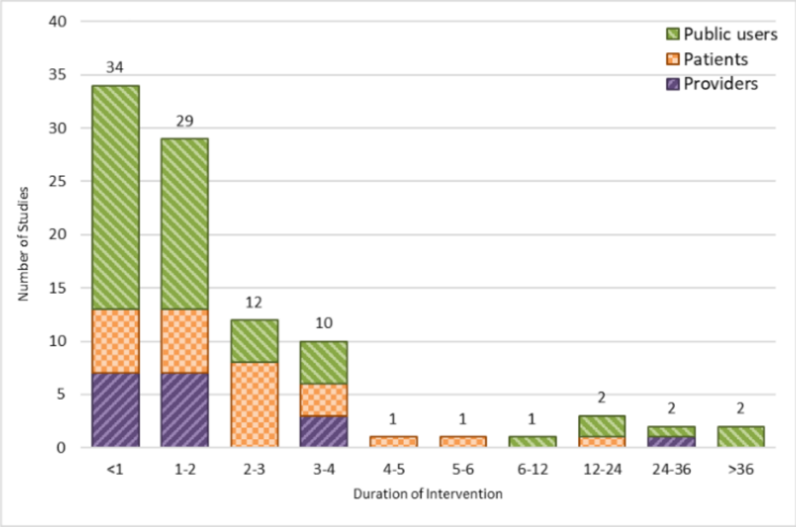
Figure 8. Number of game repetitions across the studies (stratified by user groups). Studies with missing game repetitions are not shown (n=100).



Duration of Intervention

The duration of intervention was mentioned in 94 of the reviewed studies (Figure 9). The duration of intervention varied between 1 week and 8 years. Most studies (34/94, 36%) had a time range of less than 1 month.

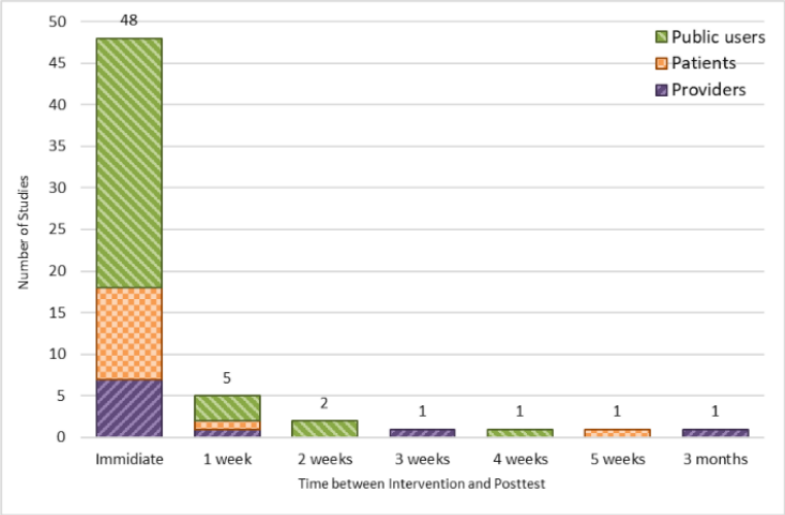
Figure 9. Duration of intervention in months (stratified by user groups). Studies with missing duration of intervention are not shown (n=67).



Time Between Intervention and Posttest

The time between intervention and posttest was reported in 59 (59/161, 36%) of the reviewed studies (Figure 10). Two categories of time between intervention and posttest were seen: (1) conducting a test right after the intervention (48/59, 81%) and (2) conducting a test after at least 1 day is passed from the intervention (11/59, 18%). The time ranged between 1 and 12 weeks among the latter group of studies.

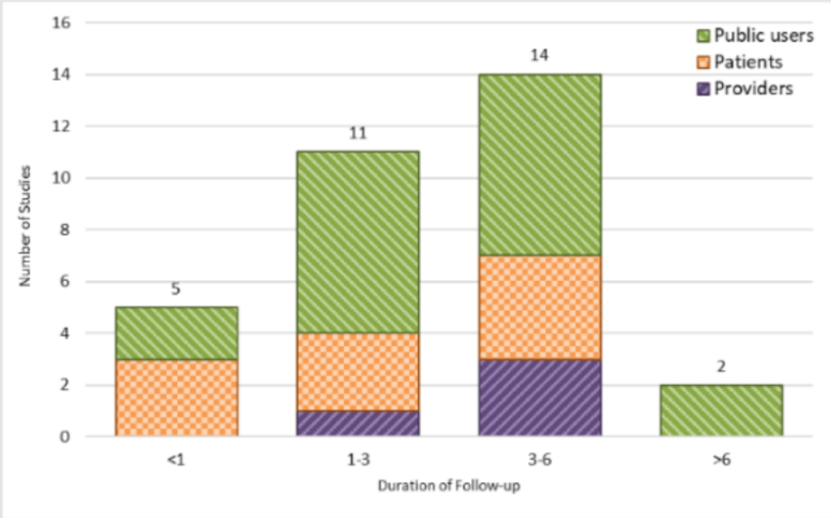
Figure 10. Time between intervention and posttest (stratified by user groups). Studies with missing information are not shown (n=102).



Follow-Up Duration

Follow-up duration was collected by a few of the studies (32/161, 19%; Figure 11). Among these studies, 97% had a follow-up duration of 1 week to 6 months. Only 1 study reported a 2-year follow-up period.

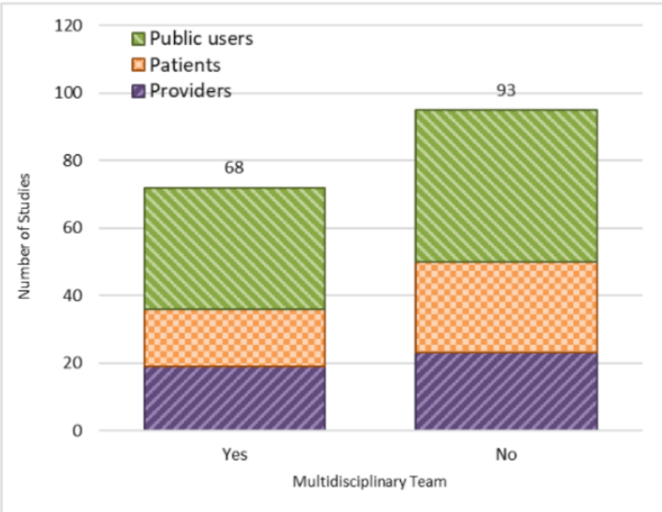
Figure 11. Duration of follow-up in months (stratified by user groups). Studies with missing follow-up duration are not shown (n=129).



Multidisciplinary Teams

Although the use of multidisciplinary teams to design health games is strongly recommended, only 42% (68/161) of the reviewed games either explicitly mentioned the use of such teams or implicitly mentioned the involvement of such experts (eg, instructional, clinical, and user experience) in the development and assessment of the games (Figure 12). Analyzing the use of multidisciplinary teams over the years of publications did not show any significant trends.

Figure 12. Development of studies by multidisciplinary teams (stratified by user groups).



Discussion

Principal Findings

Serious games are increasingly recommended as effective techniques to improve health education [23-25]. Multiple studies have assessed educational serious games in different fields of health, ranging from preventative screening to management of chronic diseases [9,26-28]. Over the last decade, a growing number of these studies have measured the efficiency and effectiveness of serious health education games using randomized trials of patients and clinicians [29-35]. Our review provides an updated scoping review of the underlying patterns and gaps of studies assessing the value of serious games in improving health education for health care providers, patients, and public users.

Serious Game Development, Target Groups, and Topics

Our results confirm the concentration of educational health game development in developed countries of North America, Europe, and Asia, thus lacking the opportunity to target educational needs of low-income countries by adopting contextualized or localized serious games. Given the increased availability of smart electronic devices and the penetration of the internet in developing countries [36], more research is needed to develop and assess the impact of serious games targeting specific health educational needs of such populations (eg, infectious diseases) [37]. Given the peak of health game development in recent years (between 2015 and 2018) and the potential higher commercialization of such solutions, focusing on emerging topics of developing countries can benefit larger populations in need [38].

Our results show that more than one-fourth (26.1%) of the health education games focused on higher education needs and targeted medical students and staff. The fact that most of these studies are using health games as an intervention and a considerable number of them have assessed their effectiveness using experimental designs (including randomized trials) provides a growing opportunity to assess the effectiveness of such serious games. It can be anticipated that medical schools (especially in North America and developed countries of Europe and Asia) will gradually incorporate such interactive solutions (ie, serious games) in their common educational curriculum in the near future. In addition, given the low cost of technology needed to use such games in medical and nursing schools, open source or free versions of such serious games can tremendously help reducing educational disparities in clinical sciences among low-resource countries.

An interesting trend revealed by our results is the gradual move from developing disease-specific serious educational games (eg, educational games for diabetes) to targeting broader public health topics (eg, safety and nutrition). Given the impact of health topics such as safety and nutrition on population-level outcomes, the future of educational health games may entail a larger coverage of the general healthy population rather than patients with specific diseases (ie, helping to bridge pubic and population health outcomes [39,40]). The wider target groups of end users can potentially translate into increased market opportunities for educational health games as well as sustainable commercialization over the long term.

Game Design and Learning Outcomes

Educational games primarily aim to increase awareness and knowledge among the players. Nonetheless, the ultimate goal of educational *health* games should include a behavioral change in the end users, thus producing a lasting effect. Developing such complex health education serious games, however, is challenging as it requires the participation of multidisciplinary team members to address various game play perspectives, ranging from principles of design to psychology of behavioral change. In this review, the evaluation of the studies revealed that the use of multidisciplinary teams to design health education games is strongly recommended, but it is accomplished occasionally by game developers. Indeed, according to our evaluation, almost half of the studies were deprived from a multidisciplinary team. Continuous collaborations among the members of the multidisciplinary expert team in addressing various aspects of game design and development are strongly recommended to improve the educational experience of the users and potentially improve the impact of health education games.

Most studies reviewed in this study had a short duration of game play with minimal repetitions and limited follow-up periods. In addition, 6 studies did not report an effective intervention and could not achieve desired educational outcomes. These limitations can be attributed partly to the lack of expert user experience designers participating in the study teams [41]. Furthermore, although factors, such as time of intervention, time between intervention and posttest, and duration of follow-up, are critical in achieving long-term knowledge gains, generalized evidence on what factors with what frequency and length works for what age-range is still lacking. More work is needed to established common design guidelines on how to engage different user groups with best game specifications for health education for both patients and medical staff groups.

Comparison With Prior Work

Previous scoping reviews of health games included all types of serious games, ranging from educational to behavioral change and exercise-focused games [4,5]. Several reviews have predominantly focused on chronic diseases [42-44], whereas other reviews have focused on specific subgroups of educational games, such as games targeting clinical staff and students [10,12,14,45] or patients with distinct medical conditions or diseases (eg, diabetes, asthma, or obesity) [46-53]. Owing to either inclusivity (all health games) or exclusivity (specific educational games) of the previous reviews, these reviews do not reveal the overall trends in educational health games across various target users (ie, health care providers, patients, and public health users). This study provides a fresh review on the latest developments and trends in serious games targeting health education, regardless of the target population or observed clinical context.

Limitations

Our work had multiple limitations. First, we specifically narrowed our search on educational serious games for health. Our review should not be considered a systematic review of all types of health games. Second, our review did not conduct a statistical analysis to measure significant differences among various target groups (eg, measuring significant differences between patients and public health users). Third, we did not perform a meta-analysis, as the studies did not report enough details about their population to perform such analysis. In addition, the outcomes of interest varied greatly, and a meta-analysis was not appropriate for our review. Fourth, we only included English publications, thus unavoidably excluded studies that might be conducted and published in other developed countries not using English as their primary scientific language. Fifth, the variability of reviewed studies limited our review to encode generic specifications, such as publication date, study location, and target groups. More research is needed to tease out the details reported by various subgroups of these studies (eg, some studies reported exact outcomes of interest). Finally, we used PubMed and ScienceDirect as our search engines; however, other search engines might provide additional studies not indexed in the aforementioned databases.

Future Work

Future work should include a larger *systematic* review, including additional search engines and, perhaps, focusing on the educational games designed for either patients or clinical providers. Additional work on reviewing educational outcomes of interest among these studies and the effectiveness of the health games in achieving them is also needed.

Conclusions

Serious games are increasingly used for health education. This study offers an updated scoping review of the studies assessing the value of serious games in improving health education. Most educational health games are still developed in high-income countries, but a surge of new games focusing on healthy behaviors (eg, nutrition and safety) has been observed in the last 5 years. Game developers need to use multidisciplinary teams to improve the design of the serious games in keeping the end users engaged for a longer interaction and potentially more effective educational health outcomes. Investment in serious games, as a low-cost educational tool for both patients and medical providers, can potentially help to fill the gap for health education in developing countries.

Conflicts of Interest

None declared.

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Viewpoint

Using 360-Degree Video as a Research Stimulus in Digital Health Studies: Lessons Learned

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Abstract

Due to the accessibility of omnidirectional cameras to record 360-degree videos and the technology to view the videos via mobile phones and other devices, 360-degree videos are being used more frequently to place people in different contexts and convey health-related information. Increasingly, 360-degree videos are being employed in health marketing because they have the potential to enhance health-related attitudes and behaviors. As a case study on how this technology may be used for health-related information and its effect on health care providers, we created a 360-degree video that portrays the experience of a migraine sufferer to be used as a stimulus in an online study. We describe the challenges and lessons learned in designing and implementing a 360-degree video as part of an online experiment focused on inducing empathy among clinicians for understanding patient experience. Given the rapid change in digital technology, future research can use this knowledge to design and implement 360-degree video studies more effectively.

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KEYWORDS

virtual reality; 360-degree video; empathy; migraine disorders; health personnel; medical education

Introduction

An accessible form of virtual reality (VR) technology is 360-degree video. For the public, 360-degree videos are more accessible than other VR technologies because they can be viewed on many common devices, including head-mounted display (HMD) VR headsets, computers, and mobile devices, and because of the technology used to create them. For content creators, 360-degree videos are more accessible because the equipment and labor costs to produce them are lower. For these reasons, 360-degree videos are becoming a more common mode of marketing and communicating information.

To create 360-degree videos, omnidirectional cameras are used to simultaneously record a view from every direction. Users can replicate the way they would change their field of view using their body in the real world by moving the device or clicking the screen. The audience is limited to an omnidirectional view from predetermined standpoints in 360-degree videos, unlike other virtual reality systems that allow users to move throughout a virtual environment. Despite this limitation, 360-degree videos are capable of immersing their audience in a virtual world.

One of the most important capabilities of VR is to transport and fully immerse viewers into a new experience or environment [1]. Similar to traditional narratives and immersive physical environments, immersive technologies permit a sensation of presence. However, immersive technologies may be uniquely capable of helping users feel like they are actually in the environment and experiencing the situation by taking the perspective of the actor. Evidence has shown that immersive technologies can elicit emotional reactions such as empathy [2,3] from users and affect behavior change [4]. Storytelling and reporting using 360-degree video can produce a higher empathic response, immersion, and engagement than text news depicting the same event [5]. In addition, 360-degree video has gained traction in marketing and advertising because it elicits more positive emotion compared with traditional video [6,7]. For example, pharmaceutical companies are starting to use immersive environments in physician-targeted marketing because they may help providers better understand the patient experience. Further, activating empathy through 360-degree video can make the viewer more susceptible to messaging in advertisements that can potentially enhance attitudes and behaviors [8]. Some examples of VR experiences developed by pharmaceutical and medical advertising companies include increasing empathy for migraine sufferers [9] and retinal disease [10].

Because it can place people in unfamiliar environments and experiences, 360-degree video is especially relevant for research focused on understanding how people react to new information or diverse health situations [11]. However, most research is limited to laboratory settings where it is easier to implement the delivery of the video and assess participants reactions. To investigate real-world responses to 360-degree video, an “in the wild” approach is needed to include a larger and more diverse group of people.

This approach can be challenging because of the diverse settings and devices participants may use to view the stimuli [12]. Some researchers purport that HMDs are the most immersive [1]. Several studies have found that HMDs are more effective at eliciting affective responses than a two-dimensional nonimmersive VR interface, personal computer (PC) monitors [13-15]. However, this does not imply that users viewing a 360-degree video on a PC monitor do not feel immersed. One study found that HMD elicited a greater sense of presence than a PC monitor but that the PC monitor was still able to elicit a high sense of presence [13]. Although HMDs may be highly immersive and effective at creating feelings of presence [4], HMDs have limited use in an “in the wild” approach because of costs and availability. Additionally, the novelty of using HMDs can decrease recall [16].

In time, 360-degree videos may become an important medium for studying how different environments and experiences affect behavior and other outcomes. For example, as 360-degree video messaging becomes more ubiquitous, research studies using 360-degree videos as stimuli will be necessary in order to understand how the medium engages viewers and influences their perceptions toward health-related products or influences behaviors among diverse populations. In order to use 360-degree videos as research stimuli in real-world settings, researchers first need to understand how 360-degree videos can be implemented in the real world and how these settings affect proximal outcomes such as immersion, presence, and empathy. To fill this gap, we present lessons learned from an online study examining the effect of a 360-degree video depicting a migraine episode from the sufferer’s point of view on physicians’ empathy compared with a first-person written narrative describing the same experience.

Methods

We created a 360-degree video that portrays the light and sound sensitivity experienced by migraine sufferers. The content of the video was based on similar videos created by pharmaceutical companies. The video was filmed using an Odyssey (GoPro Inc), a custom camera rig using 16 individual, tethered GoPro cameras designed for Google’s Jump platform. The video was created internally by AK and the John Bollenbacher Multimedia Communication Services department at RTI International.

We fielded the experiment for 3 weeks. Primary care physicians (PCPs) were recruited through an online survey panel vendor, Dynata [17]. Participants included 155 PCPs randomly assigned to 1 of 2 conditions. PCPs assigned to the 360-degree video condition watched a 2-minute 360-degree video portraying what it is like for someone suffering from a migraine at work. PCPs assigned to the narrative condition read a short story about a person’s experience with a migraine at work that mirrored the experience portrayed in the 360-degree video. We then asked all participants to report their feeling of empathy and immersion in the story/video. State empathy was measured using a scale adapted from Shen [18]. The items within the scale were closely correlated in this study, with an alpha of 0.837. To derive the lessons learned, we draw on the results from PCPs assigned to the 360-degree video condition (n=77). The mean age of the 360-degree video condition participants was 49.5 years (SD 10.1, range 30-88), 57% (44/77) were male, and most were non-Hispanic white (45/77, 60%). Below we report on our lessons learned in developing the video and implementing it as part of an online experiment.

Development

Virtual Effects

We used After Effects (Adobe), a visual effects and compositing application, to portray the sensory experience of a migraine in a realistic manner. The monoscopic 4k footage was edited in Premiere Pro (Adobe), a video editing application, and then imported into After Effects. In After Effects, multiple stock “steam” elements were composited—layering video clips/instances with transparent background—on top of the espresso machine to represent a subtle increasing stressor to our “barista” neglecting the machine. All light sources in the scene, such as the overhead lights and the sun coming through windows, were masked and given a glow effect, making the light blurry, soft, and expansive to represent the visual sensitivity experienced of a migraine. This was gradually increased throughout the scene. Animated energy effects, such as separate looped video clips, were adjusted to represent white flaring and then composited directly over the already glowing light sources. They were timed to appear midway through the scene. Finally, toward the end of the scene, colorful “coma halo” animations were composited to emanate from the light sources but covered a broader area of the frame to represent a severe visual disturbance for the viewer/barista. The footage was then imported to Premiere for additional color correction, where the entire scene gradually becomes harsher with more contrast and unnatural hues.

Text Placement

Our 360-degree video starts with a brief text introduction describing the scenario to orient the viewer to the context. Using text in 360-degree video stimuli is challenging because it needs to be placed in a location that is visible from all directions, small enough that the text can be read without changing perspective, and large enough that it can be easily read on mobile device screens. We decided to place the text at 0 and 180 degrees so that part of the text would be visible at any perspective, directing the viewer to change their orientation to view the entire message. We reached this decision after an attempt to place text at more locations in the 360 sphere, which resulted in multiple partial instances of the text being visible by the viewer at one time and proving to be a distraction and an improper introduction to the 360 experience.

File Size and Format

Although we captured our video at 8k (8192×8192) resolution, viewing platforms such as YouTube and Vimeo do not support such resolutions. Most internet connections and computer processors are also not capable of playing back the content in real time; consequently, 4k was selected as an appropriate and scalable resolution. Also, the file size had to be small enough to support streaming through Wi-Fi and cellular networks and to allow enough resolution to view the text and scenes. The 360-degree video was edited and exported to MP4 files, a common video and audio format supported by popular video platforms such as YouTube and Vimeo.

Implementation

We successfully conducted an online experiment using 360-degree video as stimuli with very few technical issues. In this section we describe the technical challenges of using 360-degree video in Web surveys and the evidence that we considered when deciding on eligibility criteria based on device type and headphone availability. The results describing the impact of device type and headphone use are shown in Table 1.

Table 1. Empathy and engagement for 360-degree video by device type and headphone use.

Item	All (N=77), mean (SD)	Device type		Headphones	
		Desktop/laptop (n=48), mean (SD)	Mobile/tablet (n=29), mean (SD)	No (n=31), mean (SD)	Yes (n=46), mean (SD)
Total time viewing stimuli (seconds)	162.8 (86.2)	171.7 (100.7)	148.0 (52.8)	154.1 (67.7)	175.7 (108.0)
Rating of quality[a]	8.3 (1.6)	8.5 (1.5)	7.9 (1.8)	8.3 (1.6)	8.2 (1.7)
Immersion (I felt immersed in the [video/story].)[b]	3.1 (0.8)	3.3 (0.8)[c]	2.8 (0.8)[c]	3.1 (0.8)	3.1 (0.9)
Empathy[b]					
I could feel the person’s emotions	3.0 (0.9)	3.1 (1.0)	2.8 (0.9)	3.1 (0.7)	2.9 (1.1)
I can understand what the person was going through	3.2 (0.9)	3.4 (0.8)[c]	2.9 (1.0)[c]	3.3 (0.9)	3.2 (0.9)
I can relate to what the person was going through	2.9 (1.2)	3.1 (1.1)	2.7 (1.2)	3.0 (1.1)	2.9 (1.2)
I can identify with the person	2.7 (1.2)	2.7 (1.3)	2.6 (1.1)	2.8 (1.2)	2.6 (1.2)
Stimuli engagement[d]					
The video is memorable	4.1 (0.8)	4.2 (0.7)	3.9 (0.8)	4.1 (0.7)	4.1 (0.8)
The video is misleading	2.2 (0.7)	2.2 (0.8)	2.3 (0.8)	2.2 (0.8)	2.3 (0.7)
The video is informative	3.9 (0.7)	4.1 (0.7)[c]	3.6 (0.7)[c]	3.9 (0.6)	3.9 (0.8)
The video held my attention	4.2 (0.7)	4.3 (0.7)	4.0 (0.8)	4.2 (0.8)	4.2 (0.7)
I liked the video	3.9 (0.8)	4.0 (0.9)	3.7 (0.7)	3.9 (0.8)	3.9 (0.9)
Watching the 360-degree video changed the way that I think about migraines.[d]	3.5 (0.8)	3.6 (0.8)	3.4 (0.8)	3.3 (0.9)[c]	3.7 (0.8)[c]

[a]Participants rated two quality items on a scale of 1 to 5, with 1=low quality and 5=high quality. These items were summed to create a single quality rating with a range of 2 to 10, with 2=low quality and 10=high quality.

[b]Participants rated items on a scale of 0=not at all to 4=completely.

[c]Denotes a significant difference between groups (P<.05)

[d]Participants rated items on a scale of 1=strongly disagree to 5=strongly agree.

Hosting Platform

The 360-degree video technology is relatively new and is not supported by online survey platforms, including the survey platform Qualtrics used in this study. A 360-degree video must be hosted on an outside platform and also be embedded within the survey. We considered five 360-degree video hosting platforms, which are shown in Table 2. We selected OmniVirt Premium because of its hosting capabilities, player customization, and mobile device support. When considering options for hosting and embedding 360-degree video, it is important to consider hosting, player customization, and mobile device support.

Table 2. Comparison of 360-degree video Web embedding options as of September 2018.

Platform	Cost	Supported mobile operating systems[a]	Video hosting	Player customization[b]
YouTube	Free	Android	Yes	Limited
Vimeo	$7.99/month	Android	Yes	Full
Google VR View for the Web	Free	Android, iOS	No	Full
OmniVirt (Basic)	Free	Android, iOS	Yes	None
OmniVirt (Premium)	$500/month	Android, iOS	Yes	Full

[a]All options considered support for 360-degree video embedding on all PC operating systems.

[b]Full player customization allows users to remove the logo, disable links to open video on platform, and disable full-screen view for optimal embedding for research.

Videos can be hosted on a private server and embedded using Google VR View or uploaded to an all-in-one hosting and 360-degree video player platform. To save on costs and mitigate technical issues playing the video, we wanted to use a platform that could also host 360-degree video. OmniVirt Premium provided video hosting.

In terms of player customization, many video players allow users to click a logo embedded in the player to view the video on the platform's website. On some platforms, clicking the full-screen option also opens the video in a new browser window. We needed to disable these options for three reasons. First, opening the video in a new window allows anyone to copy the link and share it with others. Second, participants may not be able to navigate back to the survey to complete the questionnaire. Third, participants would be able to view the video again while completing the survey. OmniVirt Premium allowed us to customize the player to disable the full-screen mode, remove the OmniVirt logo, and disable links.

Regarding mobile device support, many 360-degree video platforms do not support embedded 360-degree video for iOS because of limitations inherent in the Apple iOS operating system. Users must often download the platform app to view the video. We decided to select a platform that supported iOS embedded video because of the popularity of iOS devices. OmniVirt was the only platform that supported Web-embedded 360-degree video playback on iOS devices.

Connectivity/Stimuli Viewing

Participants can access an online survey using a wide array of devices, browsers, and internet connection speeds. Technical issues or limited bandwidth can cause videos to play choppily or to not play at all. Additionally, participants could potentially skip the video altogether and proceed with the survey. We added several safeguards to ensure that participants watched the video. We disabled the Next button from appearing on the survey screen for 110 seconds, the approximate length of our video. On the same survey screen, we used JavaScript to update a hidden variable each time the play button was clicked.

We also added two questions immediately after the stimuli asking participants to confirm whether they were able to view the 360-degree video, and if they were not able to view it, what technical issues they encountered. All participants who answered that they were not able to view the video were terminated and excluded from analysis. Only one participant was unable to view the video. All participants randomized to the video condition clicked play at least once.

Device Types

The ability to play 360-degree videos on computers, mobile devices, tablets, and HMD has made 360-degree video more accessible. For research purposes, different device types can confound the results because the different mediums may provide varied levels of immersion and presence because of screen size and video controls. For example, laptop users must click and drag the screen to change perspective, whereas mobile device users only need to change the orientation of their device. Randomized assignment of device type is not an option when conducting online panel research, so eligibility criteria must be limited to participants using a certain device or the device type must be controlled for during analysis.

Prior research has labeled computer monitors as nonimmersive [1] and found that HMD offers a more immersive experience than computers [8,9]. Other research explored the type of viewing platform—such as smartphone with an HMD and smartphone without an HMD—on users' experiences of immersion and found that adding an HMD to a smartphone did not necessarily lead to more empathy or greater interest in the 360-degree video [3]. Given this, we considered limiting eligibility to mobile device and tablet users. However, because research on the impact of the type of device is equivocal, we opted to include a question asking participants to indicate their device type and explore whether the type of device had a significant effect on any of our key outcomes.

Approximately a third of our final participants (29/77, 38%) viewed the 360-degree video on a tablet or mobile phone, with a majority of participants (48/77, 62%) viewing the video on a laptop or desktop computer. Compared with participants who viewed the video on a tablet or mobile device, participants who viewed the video on a desktop or laptop computer reported significantly greater levels of immersion (mean 3.3 [SD 0.8] vs mean 2.8 [SD 0.8]) and agreement on one dimension of empathy, "I understand what the person in the video is going through" (mean 3.4 [SD 0.8] vs mean 2.9 [SD 1.0]), as shown in Table 1. Choosing not to exclude desktop and laptop users increased the generalizability of our results and improved our participation rate, given the availability of 360-degree video on these devices. Additionally, it appears that viewing the 360-degree video on a desktop or laptop may have been more immersive and impactful than viewing it on a mobile device. Research is needed on the relative immersiveness of mobile devices and laptops and desktops.

Headphones

Some evidence indicates that using headphones can have an impact on viewers' immersion in 360-degree videos [19]. We considered adding headphones as a requirement for participation because sound is an integral part of the migraine experience. However, we decided instead to allow users with and without headphones to examine if there was any difference in response to the video. In our instructions, we prompted participants to use headphones or to turn the volume up to 100% if they did not have headphones available. We also asked participants to report whether they had used headphones or not.

A majority of participants used headphones (46/77, 60%). Participants who wore headphones were more likely to agree that watching the 360-degree video changed the way they thought about migraines (mean 3.3 [SD 0.9]) as compared with participants who did not use headphones (mean 3.7 [SD 0.8]; Table 1). We found no significant differences between participants who used headphones and participants who did not use headphones on any other items of engagement, empathy, or immersion. Although there was no association between these outcomes and headphone use, our findings illustrate that a majority of participants had access to headphones and were willing to use them—consequently, including instructions to prompt participants to do so may be advisable—and that wearing headphones may bolster the persuasive power of 360-degree video.

Conclusion

Given the potential challenges that can arise when creating 360-degree video content and implementing an online experiment using 360-degree video as stimuli, our study found that 360-degree video stimuli must be designed so that essential elements are seen by all viewers, regardless of perspective. The video also must be edited and encoded in a format that allows for playback on common video players and in a resolution that allows participants using a variety of screen sizes to clearly view the scene. The file size of the video must also be small enough to avoid long download or buffering times. Researchers will need to carefully select the survey and video platforms so that all eligible participants can view the stimuli. It also is important to confirm participants actually viewed the stimuli by using embedded variables and follow-up questions. As 360-degree video technology advances, new challenges no doubt will be introduced; however, some of the challenges presented here can be addressed.

Future research also should address the impact of device type and headphone use on empathy and engagement. In this study, we found that laptop and desktop users reported greater levels of empathy and engagement as compared with mobile and tablet device users. Prior research has compared HMD to these types of devices, but no research has looked at the difference between computers and mobile devices, two of most common ways that the general public accesses 360-degree video. Finally, we found that using headphones does not affect most outcomes.

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Conflicts of Interest

None declared.

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Abbreviations

HMD: head-mounted display
PC: personal computer
PCP: primary care physician
VR: virtual reality

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