JMIR Serious Games

Journal Impact Factor (JIF) (2023): 3.8
Volume 5 (2017), Issue 1 ISSN 2291-9279 Editor-in-Chief: Gunther Eysenbach, MD, MPH

Contents

Original Papers

Original Paper

Development of an Educational Game to Set Up Surgical Instruments on the Mayo Stand or Back Table: Applied Research in Production Technology

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Abstract

Background: Existing research suggests that digital games can be used effectively for educational purposes at any level of training. Perioperative nursing educators can use games to complement curricula, in guidance and staff development programs, to foster team collaboration, and to give support to critical thinking in nursing practice because it is a complex environment.

Objective: To describe the process of developing an educational game to set up surgical instruments on the Mayo stand or back table as a resource to assist the instructor in surgical instrumentation training for students and nursing health professionals in continued education.

Methods: The study was characterized by applied research in production technology. It included the phases of analysis and design, development, and evaluation. The objectives of the educational game were developed through Bloom's taxonomy. Parallel to the physical development of the educational game, a proposed model for the use of digital elements in educational game activities was applied to develop the game content.

Results: The development of the game called "Playing with Tweezers" was carried out in 3 phases and was evaluated by 15 participants, comprising students and professional experts in various areas of knowledge such as nursing, information technology, and education. An environment was created with an initial screen, menu buttons containing the rules of the game, and virtual tour modes for learning and assessment.

Conclusions: The "digital" nursing student needs engagement, stimulation, reality, and entertainment, not just readings. "Playing with Tweezers" is an example of educational gaming as an innovative teaching strategy in nursing that encourages the strategy of involving the use of educational games to support theoretical or practical classroom teaching. Thus, the teacher does not work with only 1 type of teaching methodology, but with a combination of different methodologies. In addition, we cannot forget that skill training in an educational game does not replace curricular practice, but helps.

(JMIR Serious Games 2017;5(1):e1) doi:10.2196/games.6048

KEYWORDS

nursing education research; educational technology; perioperative nursing

Introduction

Education, in an enlarged view, covers the formative processes that occur at work in school learning and human coexistence. Current research suggests that digital games can be used effectively for educational purposes at any level of training [1,2].

In 2015, the Horizon Report identified game-based learning as an area likely to have major impact on learning in the next 2 years. The discovery of this report is indicative of the growing interest in the use of digital games technology with effective projection in education [3].

An educational game is defined as an instructional method, which requires that the learner participates in a competitive activity with preset rules [4]. With educational games, learners have an opportunity to experiment with decision-making and problem-solving in a risk-free active learning environment [5]. Therefore, educational games are considered experiential learning methods that may contribute positively to students' learning.

Generally, educators use active learning approaches to keep up with new interesting data, promote information retention, and stimulate critical thinking. This is especially important when the subject is complex or tedious [6].

Surgical centers are considered high risk scenarios extremely susceptible to errors dominated by pressure and stress [7,8]. It is well known that students from different fields of medical science are exposed to several stress factors throughout clinical education processes inside the operating room [9-11]. The level of anxiety can increase when some factors are associated [12], such as interpersonal communication, humiliating experiences, educational environment, clinical experiences, and unpleasant emotions [10].

Perioperative nursing has a serious agenda with significant content that can be adapted to the game environment for teaching, improving proficiency and self-development, and conducting outcomes of research for best practices and improvement initiatives. The prospect of using serious games creates an exciting—and maybe for some, a frightening—future for those who face this oncoming technology [13].

Perioperative nursing educators can use games to complement curricula in guidance and staff development programs, foster team collaboration, and give support to critical thinking in nursing practice because it is a complex environment [6].

If a serious game could help nurses overcome fear of new procedures, learn changes in the sequencing of events, reduce the stress of a situation, or help prevent errors, then the patient will be the ultimate winner [13].

In this context, the search for quality education of health professionals and their services is based on guidelines. As an example, we mention the Safe Surgery Saves Lives campaign, whose main objective is to improve the safety of surgical care around the world by defining a core set of safety standards that can be applied in all countries and settings. The protocol includes the prevention of infection in surgical sites, safe anesthesia, safe surgical teams, and surgical care indicators [14]. The idea is that the educational game can help in this search process for excellence in teaching in the care of surgical patients.

An example in international literature in the surgical nursing area is the QuizBowl game that was presented at the Annual Congress of the Association of Perioperative Registered Nurses 2003 to 2010 [6]. Moreover, in the general nursing area, a Jeopardy-style game called "Nursopardy" is used to reinforce the fundamentals of nursing material, aiding in students' preparation for a standardized final exam [15]. Still under development is an in-home and community care settings game [16]. The e-Baby Serious Game was built to feature the simulated environment of an incubator, in which the user performs a clinical evaluation of the respiratory process in a virtual preterm infant [17]. LISSA is another serious game that considers all the steps of the cardiopulmonary resuscitation (CPR) flowchart [18].

Thus, the aim of the study was to describe the process of developing an educational game to set up surgical instruments on the Mayo stand and back table as a resource to assist the instructor in training nursing students and health professionals in continued education.

Methods

Study Design

The study was based on applied research in technology production [19], which was adopted because it dealt with the process of developing or creating a new product, activity or service, namely, a learning management system in nursing where the theme was to develop an educational game.

This study was approved by the Research and Ethics Committee of the Institute of Cardiology of Rio Grande do Sul state.

The Galvis Panqueva methodology was used to create an educational game [20] because of its clarity and cohesion, making the process more objective. This methodology comprised 3 phases: analysis and design, development, and evaluation.

A constructivist learning theory was employed to achieve the objectives of the educational game in development. This requires that learners use various tools to access content information, derive meaning, and develop knowledge of how to work through a scenario and solve given problems. Guiding this construction of knowledge, Bloom's taxonomy offers 6 levels of competencies to acquire knowledge about a topic moving from simple to complex levels: knowledge, comprehension, application, analysis, synthesis, and evaluation [21].

Parallel to the physical development of the educational game, a proposed model for the use of digital elements for educational game activities was used for the development of game content [22].

The Phases

Phase 1: Analysis and Design

The target audience, choice of subject, educational goals, outlining of the content, and technological infrastructure were defined in the analysis phase.

The target audience chosen was surgical instrumentation students and nursing health professionals in continued education.

The choice of subject was the setup of surgical instruments on the Mayo stand and the back table with basic instruments.

Thus, the educational goals for the cognitive domain were established by considering that at the end of the game, the student was able to set up surgical instruments on the table and understand the organizational sequence when applying it to the setup of the Mayo stand and back table. Additionally, the student would be able to analyze organization of the operating table, synthesize organization of the operating table in accordance with the procedure and types of instruments needed, and finally evaluate the acquisition of knowledge with increasing score.

In order to approach the subject, the content of basic types of surgical instruments and surgical time were considered important, and for the technological infrastructure, the support of a team of game designers.

In the game design phase, the proposal was to create an environment with instruments on a basic tray used in general surgery, for example, hernioplasty and postectomy, in which the student had to arrange them according to the model.

The company hired to produce the game planned the navigation structure, navigation map design, learning environment, and the interface design. As for the system tools, the need for help buttons to facilitate solving doubts was stipulated.

Phase 2: Development

The development stage in the construction consisted of an educational game developed by the researchers and 3 game designers. Its construction comprised the months of April 2015 to February 2016.

According to the proposed model for the use of gamification elements, we cite elements pertaining to this game in the following points:

Mission: To set surgical instruments on the Mayo stand or back table according to the model in virtual tour mode while considering the 6 surgical times: cutting, grasping, hemostatic, retractors, special, and suture.

Plot: In the game, the player assumes the role of a surgical nurse in the operating room. In the learning mode, the player has no specific time to finalize the setup table, but in assessment mode is given 7 minutes, with a basic instrumental tray used in general surgery (hernioplasty and postectomy). The player has to recreate a model setup of surgical instruments proposed in the virtual tour.

Character: A character called Metzenbaum was created to represent a surgical nurse.

Challenges: Increase the score with each attempt, until one reaches the appropriate level of 70% of correct positions. After placing the instruments in each step, the player has to click the correct button, which results in the following warnings: “Try again,” “Congratulations, you have reached 70% or more,” “Great you hit 100%.”

Specific objectives: Place the instruments in the location set for each surgical time.

Resources, collaboration, or help: In the virtual tour mode, the player can view the setup of the surgical table, which includes scientific and popular names and classes of instruments. In learning mode, the player can use the “hint” as many times as needed, showing the location where the instruments should be placed. In either way, the student assessment will not provide any help.

Items or bonus: For each surgical time that is completed with the instruments of the game, the player is awarded a star as a bonus; 6 stars being the maximum.

The game was developed in HTML 5 using the an computer program, which can be used on Windows, Linux, and Mac platform. The instrumental images were photos from the researcher’s personnel file and modeled in *blendere* changed in *gimp*. The game designers built the image of the avatar in surgical nursing.

The game will be hosted on the financial institution's website and a password will be provided to the user.

Phase 3: Evaluation

During the stage of the evaluation, students from the surgical instrumentation course and expert professionals in various fields of knowledge related to nursing, information technology, and education were invited to evaluate the learning environment. The evaluators comprised a nonprobabilistic convenience sample for which selection was performed using nonrandom, intentional methods [19].

A specific form based on 3 thematic areas according to the Ergolist Project was used for data collection, distinct for the different areas of professionals [23], using a Likert scale, in which the user had to mark one of the choices: “totally disagree,” “partially disagree,” “indifferent,” “partially agree,” and “totally agree.”

Health education and nursing experts, along with the students evaluated the following thematic areas: (1) *Educational aspects* (if the central theme is significant, if there is coherence of objectives, if theoretical directions are understandable, if exercises and activities are easy to understand, if valuation method is applicable, if autonomy is provided to the user, and if didactic resources helped in solving problems); (2) *Environment interface* (if navigability, accessibility, environment design, and didactic resources are easy to view); and (3) *Interactivity of the system* (if it is easy to use and navigate on the screen).

However, the specific form for information technology professionals contemplated *Response time* (referring to navigability, accessibility, and system feedback to the user); *Interface quality* (design, colors, menu, and buttons); and *Tools and resources* (form, presentation, and working operating system).

Results

Delivery of the first release of the game was in version 1.0 where there were discussions on some topics regarding the layout and background color, the slogan of the institution, use of visual and auditory feedback, and background music. This release featured the home screen, which allowed visualization of the game design with the slogan of the funding institution and a menu with 4 topics: virtual tour, learning, assessment, and credits. The topic of learning highlighted the surgical instruments of a Mayo stand at the center and a scroll bar system on the underside with the instrumentals.

On delivery of the second release in version 1.1, we included the virtual tour screen with images of the instruments, the learning screen with the scroll bar system, instruments, and signalization of hits and fails on the screen. We required adjustments in relation to the position of the instruments (closed and front position) and defined the pilot project (1st testing) with surgical instrumentation students.

The pilot group consisted of 6 surgical instrumentation students. We identified that the sample agreed 100% (6/6) totally or partially with the educational aspects. Therefore, we concluded that the central theme is significant, there is consistency of objectives, the theoretical directions are understandable, the evaluation method is applicable, exercises and activities are easy to understand, it offers autonomy and educational support, and assists in resolution. With regard to the interface, most of the sample totally or partially disagreed as follows: 83% (5/6) compared with navigability and 67% (4/6) with accessibility and design. Regarding the interactivity of the system, 50% (3/6) of the sample agreed that the game screen was easy to navigate and easy to use, but the other half disagreed with this view. The suggestions given were in improving the system, use of sound to signal the hit and fail, time to score, streamlined speed of response commands, to highlight the display of instruments, and increase the amount of tweezers.

After the study, the requests were addressed, such as sound differentiating on hits and fails, positioning and addition of instruments, time recorded on the learning screen, the sum of the points on the evaluation screen, use of 3D image, and buttons to move the instrumental.

The third release in version 1.2 was tested with surgical instrumentation students and professional experts from various fields of knowledge related to nursing, information technology, and education. There were 15 participants, which included 8 surgical instrumentation students, 4 professionals with experience in surgical instrumentation, a professor from the surgical instrumentation course, and 2 IT professionals.

We identified that the entire sample of health professionals and students agreed totally or partially with the educational aspects, showing no difference to the pilot group. With regard to the interface, there was improved acceptance with 77% (10/13) that agreed totally or partially to navigability, 85% (11/13) to accessibility, and 77% (10/13) to design. Regarding system interactivity, 100% of the sample agreed that the game screen is easy to navigate and use.

The suggestions given were to start the game with a total score and subtract points as mistakes were made. Others included: to use a stop button, increase the range of adjustment, improve the viewing tip of the instruments, provide a score below the scroll bar, use as criterion the calculation of points for accuracy and time, delete the fail sound, improve color of the screen with an updated design, adjust the resolution of the instruments, divide the table and highlight the phases, and enable musical background sound.

The IT group rated the response time, interface quality, tools, and resources. Responses showed no particularity, emphasizing that the environment was appropriate for a teaching proposal.

Use of the Galvis Panqueva methodology, in association with educational objectives and digital gaming elements, created for the educational game “Playing with Tweezers,” a virtual environment that teaches instrumentalization in an active participatory fun way. The game offers a learning and evaluation platform facilitating the teaching-learning process.

An environment with an initial screen containing menu buttons with rules of the game and the virtual tour modes, learning, and assessment was created. We used a character feature (avatar) to represent the surgical nurses. At the end of the game, if the score was above 70%, a buzzer goes off and the avatar of the surgical nurse signals, raising its hands with a happy expression. In the situation of being below a 70% score, you hear a new sound, and the avatar with hands on its face, obscures the appearance of sadly crying, highlighting the need for greater attention. The screens of the final version of the game are shown in Figures 1-5.

Figure 1. Initial screen.

Figure 2. Virtual tour mode for learning.

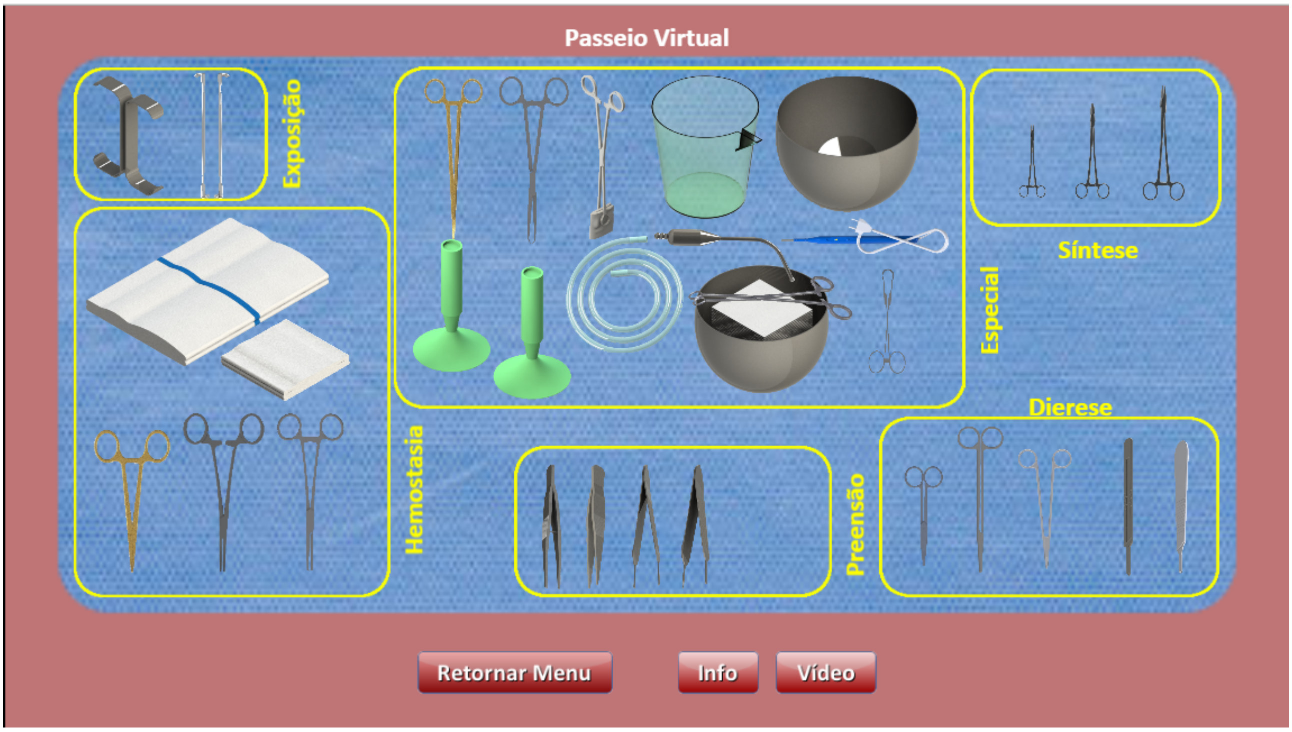


Figure 3. Instrumental in 3D.

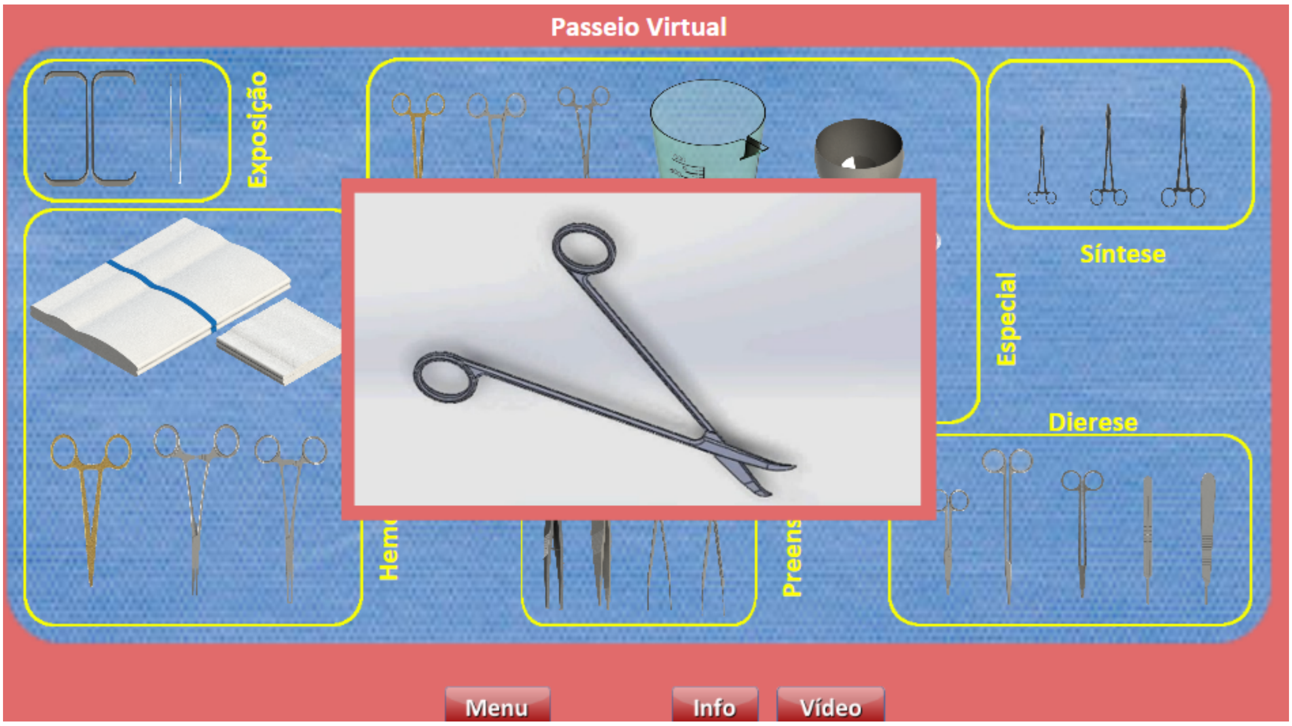


Figure 4. Virtual tour mode for assessment.

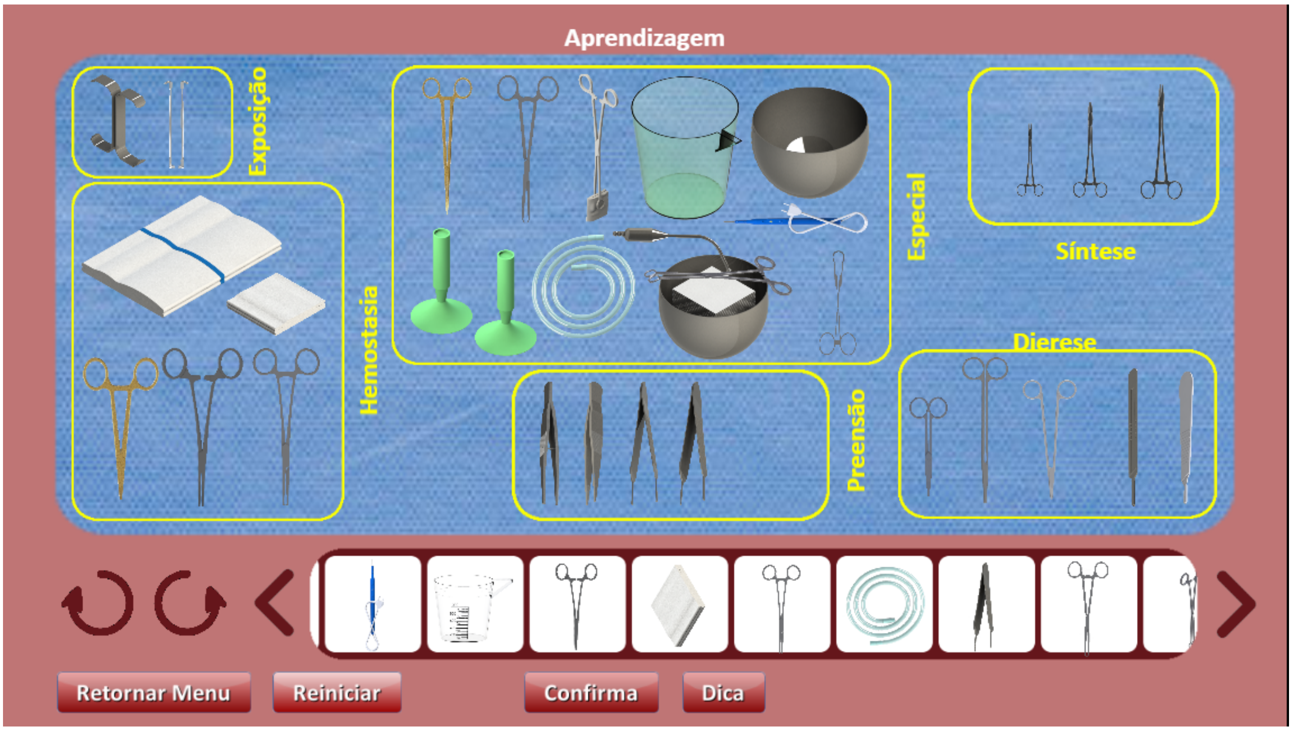
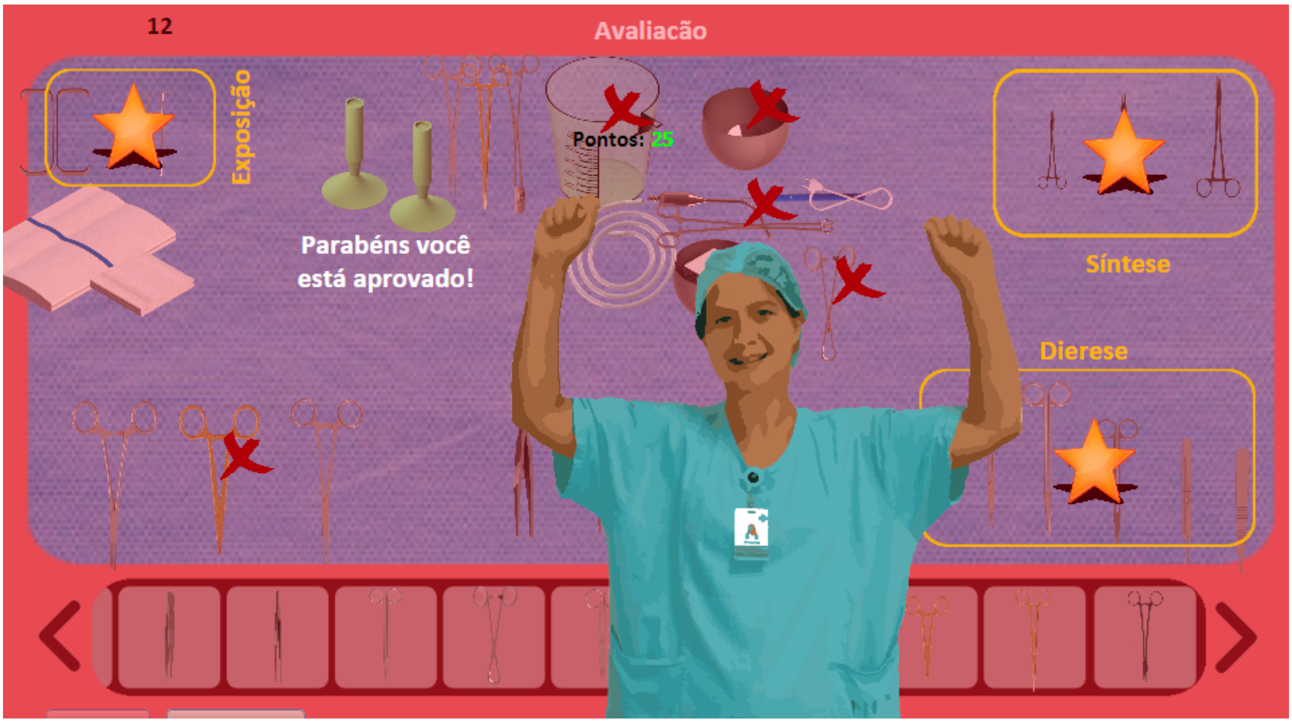


Figure 5. Final screen of the game.



Discussion

Principal Findings

The literature on the use of educational games has repeatedly shown that they have a positive effect on leaners [2,6,15,24-27]. Although this study only describes and assesses an educational game to set up surgical instruments on the Mayo stand and back table, the evaluation data of the study suggests there is some level of interest from those within the study population toward the use of a digital game to teach perioperative nursing. This preliminary finding appears to support the existing research in the area and has the potential to add data to an area of research that is underexplored.

Perioperative nursing consists in meaningful content that can be tailored to the targeted teaching game environment, improving proficiency and self-development, and the results that conduct research for best practices and improvement initiatives.

Changes in our health care system are demanding that nurses have to develop new skills and competencies. Having the opportunity to "test-out" various clinical reasoning pathways allows the practitioner to become more aware of how reason is reached and recognize the consequences of this reasoning in action [16].

In the context of medical education, there has been significant research interest in the use of digital games in clinical training, such as for surgical skills training [24]. There is also a small amount of research in the use of digital games for continued education, including studies in their usability for retraining of resuscitation skills [18,25].

For example, an article evaluated the use of LISSA, a serious game that considers all the steps of the CPR flowchart. We analyzed the effect of using LISSA after the introduction of theory and before laboratory practice. The results obtained showed that students who practiced with LISSA performed better in the laboratory sessions than students that only read theoretical material. Therefore, from the results we can conclude that the use of LISSA improves students' knowledge and skills on CPR. In addition, students feel that LISSA helps them to learn [18].

Another study created a 3D serious game for scenario-based retraining and proved to be effective in advanced life support and supported retention of acquired knowledge and skills in 3 months. The serious game, called EMSAVE, also positively engaged and motivated participants [25].

In the perioperative nursing area, 1 study describes the creation, implementation, and evaluation of a game called "Nursopardy." Nursopardy was used with first semester students in nursing classes to prepare them for the final exams. The game consisted of 5 categories with a total of 26 questions, involving care management issues, risk reduction, safety and infection control, physiological adaptation, and basic care. Research involved a small sample of 39 students, but concluded that the game is a useful teaching strategy and the students had positive evaluations. The combination of visual, sound, teamwork, and competition worked well to increase the teaching-learning process [15]. This educational game works with the objective to improve critical thinking and decision-making, and proves that there is still a gap in the literature in relation to developing skills in perioperative nursing.

The data obtained in the evaluation of students, specialists in nursing and computer areas, were extremely rewarding and fully validated the objectives of this study. "Playing with Tweezers" proved to be an intuitive virtual environment, visually pleasant, with good navigability and accessibility. It has virtual drive modes, learning, and assessment that facilitate the teaching-learning process.

Limitations

Some limitations of the study were observed in relation to the handling of this new technology as well as the use of information technology in a small sample size.

Our future work will be centered on the design of new scenarios and the introduction of new characters into the game and will assess the effect of educational gaming for the improvement of knowledge and skills.

Comparison With Prior Work

There are numerous examples of educational games that can be used in health care specialties, including jeopardy style, concentration, quiz bowls, puzzle formats, crossword puzzles, card games, board games, electronic games, slideshows, and multimedia formats. Regardless of the type of game used, it is important to carry out an assessment of knowledge consolidation [1,5]. There is limited information about the impact of these strategies on learner engagement and outcomes [26]. Further research in this area would be of benefit to both learners and educators alike [1].

A Cochrane review evaluated the effect of educational games on health professionals' performance, knowledge, skills, attitude, and satisfaction as well as on patient outcomes. Just 2 randomized controlled trials, in which the effect knowledge was not statistically different between the 2 groups, were included. The findings of the systematic review did not confirm nor refute the use of games as a teaching strategy for health professionals. More and better evidence is needed to make practice recommendations. However, those designing and implementing educational games should carefully consider their advantages and disadvantages [5].

A randomized controlled trial was conducted with 145 medical students to compare the effectiveness on the learning outcome of a game-based e-learning instruction with conventional script-based instruction in the teaching of phase contrast microscopy urinalysis under routine training conditions of undergraduate medical students. Of the total, 82 subjects where allocated for training with an educational adventure-game and 69 subjects for conventional training with a written script-based approach (script group). The students in the game group achieved significantly better results in the cognitive knowledge test than the ones in the script group. The mean score was 28.6 for the game group and 26.0 for the script group. Attitudes toward the recent learning experience were significantly more positive with the game group. Students reported having more fun while learning with the game compared with the script-based approach [2].

The gaming platform "They Know" is a strategy game based on team participation designed for use in a variety of educational curricula. In the context of this study, the platform will be used to develop a game for medical students to study anatomy and histology. The goal is to work in cooperation with teammates in order to take control of a home base opposing team across the map. To cross the map, players must answer multiple-choice questions on each node they pass, related to its specific category of learning. During the game, players will be observed by a study coordinator and will be filmed for the research team to review how the players interact with their teammates. The research team will also be working with the study participants to explore the ways in which their knowledge was structured as a result of playing the educational video game [1].

Nursing faculty at a mid-Atlantic historical black college and university introduced "serious gaming" technology to a community health nursing course by using 2 Web-based game simulations (1) Outbreak at WatersEdge: A public health discovery game, and (2) EnviroRisk. This innovation proved to be effective in reinforcing learning and improving student learning outcomes [27].

It is necessary to determine whether learning is taking place and what are the game elements that support learning. More studies are suggested to observe how active-learning strategies, such as games, affect learning outcomes, including exam scores for nursing students.

Conclusions

The “digital” nursing student needs engagement, stimulation, realism, and entertainment and not just more reading. “Playing with Tweezers” is 1 example of educational gaming as an innovative teaching strategy in nursing, as it encourages the strategy of involving the use of educational games to support the theoretical or practical classroom teaching. The teacher does not work with only 1 type of teaching methodology, but with a combination of methodologies. In addition, we cannot forget that skill training in educational games does not replace the curricular practice, but helps.

Acknowledgments

The authors would like to thank the Institute of Cardiology of Rio Grande do Sul for their ongoing support of this study.

Conflicts of Interest

None declared.

References

1. Janssen A, Shaw T, Goodyear P. Using video games to enhance motivation states in online education: protocol for a team-based digital game. JMIR Res Protoc 2015;4(3):e114. [doi: 10.2196/resprot.4016] [Medline: 26416522]
2. Boeker M, Andel P, Vach W, Frankenschmidt A. Game-based e-learning is more effective than a conventional instructional method: a randomized controlled trial with third-year medical students. PLoS One 2013 Dec;8(12):e82328 [FREE Full text] [doi: 10.1371/journal.pone.0082328] [Medline: 24349257]
3. Johnson L, Brown M, Becker S. NMC Horizon ReportHigher Education Edition. NMC. 2015. URL: http://cdn.nmc.org/media/2015-nmc-horizon-report-HE-EN.pdf [WebCite Cache ID queryphp]
4. Bastable SB. Instructional methods: Selection, use, and evaluation. In: Nurse as educator: principles of teaching and learning. Sudbury, MA: Jones and Bartlett Publishers; 1997.
5. Akl EA, Sackett KM, Erdley WS, Mustafa RA, Fiander M, Gabriel C, et al. Educational games for health professionals. Cochrane Database Syst Rev 2013;1:CD006411. [doi: 10.1002/14651858.CD006411.pub3] [Medline: 23440807]
6. Carifa L, Goodin H. Using games to provide interactive perioperative education. AORN J 2011;94(4):370-376 [FREE Full text] [doi: 10.1016/j.aorn.2011.01.018] [Medline: 21967910]
7. Fragata JIG. Erros e acidentes no bloco operatório: revisão do estado da arte. Rev. Port. Saúde Pública 2010:17-26 [FREE Full text]
8. Leape LL, Brennan TA, Laird N, Lawthers AG, Localio AR, Barnes BA, et al. The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II. N Engl J Med 1991 Feb 7;324(6):377-384. [doi: 10.1056/NEJM199102073240605] [Medline: 1824793]
9. Silva EL, Leitão GCM. Fatores que interferem no ensino e na aprendizagem no Centro Cirúrgico. Rev SOBECC 2008;13(1):32-37 [FREE Full text]
10. Zuza E, Arruda AD, Vasconcelos DD, Silva GD, Rodrigues F. Instrumentação cirúrgica e fatores que interferem na prática dos graduandos de enfermagem. Rev enfermagem UFPE 2015;9(12):9 [FREE Full text]
11. Moridi G, Valiee S, Khaledi S, Fathi M, Shafiean M, Gharibi F. Clinical education stressors from the perspective of students of nursing, midwifery, and operating room: a study in Kurdistan University of Medical Sciences. Iranian Journal of Medical Education 2012;11(7). [Medline: 26793720]
12. Carvalho R, Farah O, Galdeano L. Níveis de ansiedade de alunos de graduação em enfermagem frente à primeira instrumentação cirúrgica. Rev Latino-Am Enfermagem 2004;3(6):918-923.
13. Baker JD. Serious games and perioperative nursing. AORN J 2009 Aug;90(2):173-175. [doi: 10.1016/j.aorn.2009.07.002] [Medline: 19664409]
14. CIRURGIAS SEGURAS SALVAM VIDAS MANUAL: SEGUNDO DESAFIO GLOBAL PARA A SEGURANÇA DO PACIENTE. 2009. URL: http://bvsms.saude.gov.br/bvs/publicacoes/seguranca_paciente_cirurgia_salva_manual.pdf [accessed 2016-12-23] [WebCite Cache ID 6myXvpPal]
15. Boctor L. Active-learning strategies: the use of a game to reinforce learning in nursing education. A case study. Nurse Educ Pract 2013 Mar;13(2):96-100. [doi: 10.1016/j.nepr.2012.07.010] [Medline: 22910398]
16. Dariel OD, Raby T, Ravaut F, Rothan-Tondeur M. Developing the serious games potential in nursing education. Nurse Educ Today 2013;33(12):1569-1575. [doi: 10.1016/j.nedt.2012.12.014]

17. Fonseca LM, Dias DM, Góes Fdos S, Seixas CA, Scochi CG, Martins JC, et al. Development of the e-Baby serious game with regard to the evaluation of oxygenation in preterm babies: contributions of the emotional design. Comput Inform Nurs 2014 Sep;32(9):428-436. [doi: 10.1097/CIN.0000000000000078] [Medline: 25010051]
18. Boada I, Rodriguez-Benitez A, Garcia-Gonzalez JM, Olivet J, Carreras V, Sbert M. Using a serious game to complement CPR instruction in a nurse faculty. Comput Methods Programs Biomed 2015 Nov;122(2):282-291. [doi: 10.1016/j.cmpb.2015.08.006] [Medline: 26319184]
19. Polit D, Beck C, Hungler B. Fundamentos de pesquisa em enfermagem: métodos, avaliação e utilização. Porto Alegre: Artmed; 2004.
20. Galvis PA, Mendoza B. Ambientes virtuales de aprendizaje: uma metodologia para sucreación. Informática Educ 1999;12(2):295-317.
21. Bloom BS. Taxonomy of Educational Objectives, Handbook 1: The Cognitive Domain. New York, NY: David McKay Co. Inc; 1956.
22. Martins C, Giraffa LMM. Gamificação nas práticas pedagógicas em tempos de cibercultura: proposta de elementos de jogos digitais em atividades gamificadas. Anais do Seminário de Jogos Eletrônicos, Educação e Comunicação 2015;2015(1):1.
23. Rodrigues R, Peres H. An educational software development proposal for nursing in neonatal cardiopulmonary resuscitation. Revista da Escola de Enfermagem da USP 2013;47(1):235-241.
24. Hedman L, Schlickum M, Felländer-Tsai L. Surgical novices randomized to train in two video games become more motivated during training in MIST-VR and GI Mentor II than students with no video game training. Stud Health Technol Inform 2013;184:189-194. [Medline: 23400154]
25. Buttussi F, Pellis T, Cabas VA, Pausler D, Carchietti E, Chittaro L. Evaluation of a 3D serious game for advanced life support retraining. Int J Med Inform 2013 Sep;82(9):798-809. [doi: 10.1016/j.ijmedinf.2013.05.007] [Medline: 23763908]
26. Webb TP, Simpson D, Denson S, Duthie E. Gaming used as an informal instructional technique: effects on learner knowledge and satisfaction. J Surg Educ 2012;69(3):330-334. [doi: 10.1016/j.jsurg.2011.10.002] [Medline: 22483133]
27. Day-Black C, Merrill EB, Konzelman L, Williams TT, Hart N. Gamification: An Innovative Teaching-Learning Strategy for the Digital Nursing Students in a Community Health Nursing Course. ABNF J 2015;26(4):90-94. [Medline: 26665503]

Abbreviations

CPR: Cardiopulmonary Resuscitation

Edited by G Eysenbach; submitted 30.05.16; peer-reviewed by I Boada, M Hendrix; comments to author 18.07.16; revised version received 02.09.16; accepted 19.09.16; published 10.01.17.

Please cite as:
Paim CPP, Goldmeier S
Development of an Educational Game to Set Up Surgical Instruments on the Mayo Stand or Back Table: Applied Research in Production Technology
JMIR Serious Games 2017;5(1):e1
URL: http://games.jmir.org/2017/1/e1/
doi:10.2196/games.6048
PMID:28073736

Original Paper

Game-Based Rehabilitation for Myoelectric Prosthesis Control

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Abstract

Background: A high number of upper extremity myoelectric prosthesis users abandon their devices due to difficulties in prosthesis control and lack of motivation to train in absence of a physiotherapist. Virtual training systems, in the form of video games, provide patients with an entertaining and intuitive method for improved muscle coordination and improved overall control. Complementary to established rehabilitation protocols, it is highly beneficial for this virtual training process to start even before receiving the final prosthesis, and to be continued at home for as long as needed.

Objective: The aim of this study is to evaluate (1) the short-term effects of a commercially available electromyographic (EMG) system on controllability after a simple video game-based rehabilitation protocol, and (2) different input methods, control mechanisms, and games.

Methods: Eleven able-bodied participants with no prior experience in EMG control took part in this study. Participants were asked to perform a surface EMG test evaluating their provisional maximum muscle contraction, fine accuracy and isolation of electrode activation, and endurance control over at least 300 seconds. These assessments were carried out (1) in a Pregaming session before interacting with three EMG-controlled computer games, (2) in a Postgaming session after playing the games, and (3) in a Follow-Up session two days after the gaming protocol to evaluate short-term retention rate. After each game, participants were given a user evaluation survey for the assessment of the games and their input mechanisms. Participants also received a questionnaire regarding their intrinsic motivation (Intrinsic Motivation Inventory) at the end of the last game.

Results: Results showed a significant improvement in fine accuracy electrode activation ($P<.01$), electrode separation ($P=.02$), and endurance control ($P<.01$) from Pregaming EMG assessments to the Follow-Up measurement. The deviation around the EMG goal value diminished and the opposing electrode was activated less frequently. Participants had the most fun playing the games when collecting items and facing challenging game play.

Conclusions: Most upper limb amputees use a 2-channel myoelectric prosthesis control. This study demonstrates that this control can be effectively trained by employing a video game-based rehabilitation protocol.

(JMIR Serious Games 2017;5(1):e3) doi:10.2196/games.6026

KEYWORDS

upper limb prosthesis control; upper extremity amputees; gaming; serious games; neuromuscular rehabilitation; intrinsic motivation; EMG control

Introduction

The initial control of a myoelectric prosthesis can be a frustrating experience, especially after the already traumatic event of losing a limb. Due to the nonintuitive interface, which handles a complex mechatronic system, the cognitive demand for controlling the prosthesis is high and further delays the actual use of the device in everyday life [1,2]. At least 50% of upper extremity amputees report problems with prosthesis control and functionality [3,4], which can be attributed to the need for receiving more training in handling the prosthesis [5,6]. By providing more training opportunities, the user can fully benefit from the technical functions of the prosthesis.

To prepare the residual muscles and induce specific brain plasticity, having access to a prosthesis itself is not necessarily needed. Regaining muscle strength and coordination is a cognitively exhausting and repetitive process, during which the proper execution of movements is reestablished using surface electromyographic (EMG) feedback [2,7,8]. Through physiotherapy, patients are presented with a variety of tasks promoting the development of coping strategies for dealing with the activities of daily living, and introducing the embodiment of the prosthetic system itself. To effectively control their prosthesis, patients need to learn how to properly contract their muscles; the strength of activation and isolation of a single muscle are important parameters [1,9,10].

Although the standard rehabilitation program offers direct functional benefits, its main shortcomings are the lack of motivation for patients to pursue it without the involvement of a therapist throughout the lengthy process. In addition to the loss of functionality, patients may suffer from posttraumatic depression, further decreasing motivation for rehabilitation [11]. Transferring traditional EMG rehabilitation protocols to a virtual setting, and incorporating video games into the training process, can potentially increase the patient's engagement and perseverance [12]. This approach also provides medical professionals with quantitative data of the patient's performance.

Many studies report that the progress achieved during rehabilitation based on a playful concept is faster and superior to conservative physiotherapeutic exercises [9,13-15]. These rehabilitation games are especially popular in older adults [16], and when treating patients affected by stroke [17,18] and Parkinson's disease [19,20]. Various research groups have addressed adding virtual games to an otherwise dull routine in the area of upper limb amputee rehabilitation. There is, however, a difference between virtual or augmented reality environments and using commercially available video games during therapeutic interventions [9,21]. The latter provides greater accessibility and allows patients to easily set up the games at home, and games can be chosen that are proven to motivate the players and maintain engagement over a longer period of time [15]. An example of a commercially available video game that has been interfaced using EMG signals is *Guitar Hero* [14]. This game is based on rhythm and speed, and requires a fast reaction from the player and an immediate transmission of the processed EMG signals to the gaming system. Similarly, a rehabilitation concept for stroke patients using a modified version of the WiiMote control is used for rehab purposes of upper limb amputees, in which EMG signals are matched to the keys of the WiiMote [22]. However, controls are only limited to two motions. Other groups chose a game similar to the arcade classic *Pong*, in which the user's muscle activity is mapped into a paddle motion that hits a ball into their opponent's court [23]. Although those approaches can be motivating, the necessary actions are not very intuitive and are not directly transferable to the handling of a prosthesis [24].

This study presents an interface between a computer and a commercially available surface EMG electrode system (Ottobock Healthcare GmbH, 13E200), which is commonly used for controlling prostheses, to evaluate the short-term effects on controllability after a video game-based rehabilitation protocol.

This study, compared to previous studies, prompted participants to not only conduct repetitive agonist and antagonist muscle activation, but also to train and exert sustained contractions over a short period of time, perform precisely timed contractions, and elicit simultaneous contraction of both muscles and muscle groups. These functions are similar to how patients would control a real prosthesis as they interact with their environment.

Methods

Eleven able-bodied participants, who had no prior experience in EMG control, took part in appraising the benefits of the video game-based training. The categories of the EMG controllability assessments that were evaluated consisted of a provisional maximum voluntary muscle contraction for calibration, precision control, electrode separation, and endurance control by retracing a sine curve with the EMG signal. These assessments are further explained in detail in the *Electromyographic Assessments* subsection. Three video games and their respective control variations were evaluated for their motivational factors and feasibility. Two questionnaires were given to evaluate (1) the video games and the input method, and (2) intrinsic motivation. This study was approved by the ethics committee at the Medical University of Vienna (number 1301/2015) and all study participants read and signed the consent form before taking part.

Participants

Eleven naïve, able-bodied participants without any known neurological or muscular impairments participated in the study. All participants had normal or corrected-to-normal vision and were instructed and accompanied by the examiner throughout the entirety of the study.

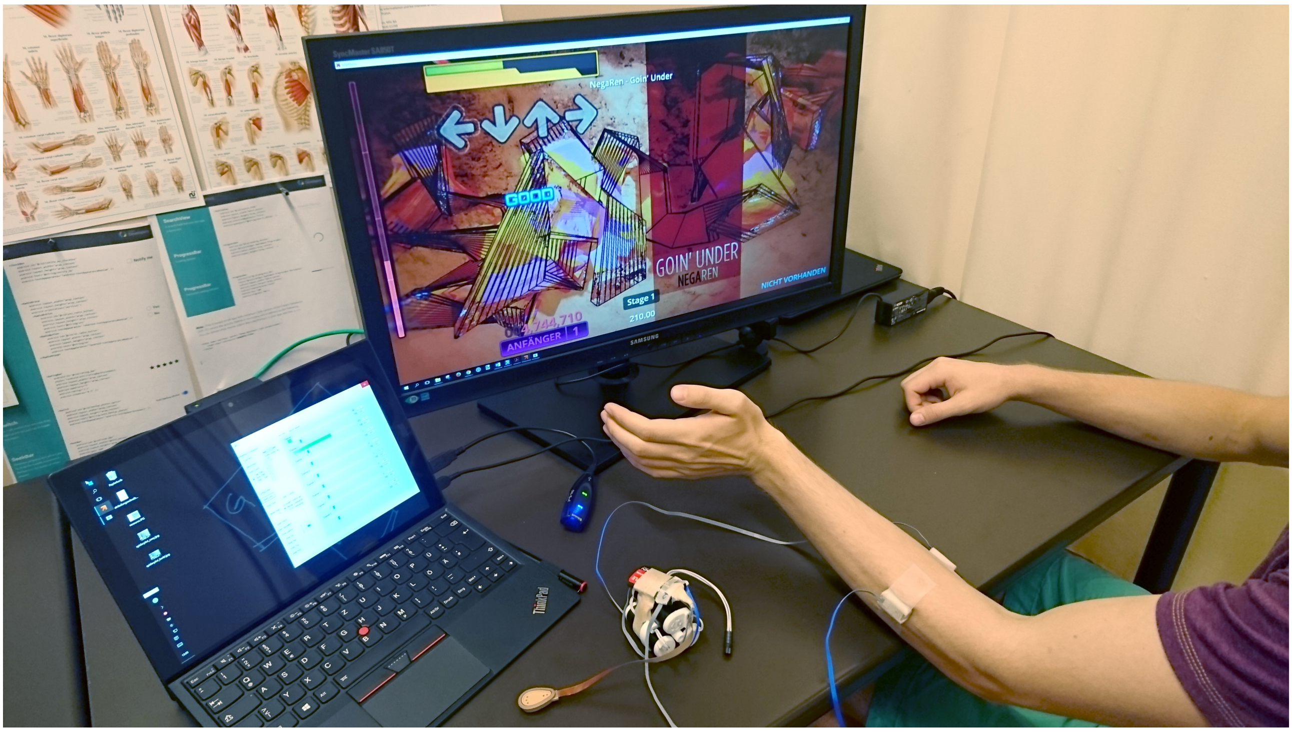
Experimental Protocol

Each participant was seated comfortably in front of two computer screens. One screen displayed the acquired EMG data per electrode channel, the other screen showed the game that the participant was playing. Two active surface EMG electrodes (Ottobock Healthcare GmbH 13E200) were positioned on top of the prominent flexor and extensor muscles of the wrist on the participant's nondominant side (see Figure 1). This was done to match the handedness of the amputees, which is always transferred on the intact limb regardless of the preimpairment state. Amplification and electrode placement remained the same throughout the sessions. Each electrode delivered root mean square (RMS) at the 100-hertz rate of the recorded EMG signal following the embedded filtering and rectification.

Participants were invited two times and had three test sessions in total: one Pregaming and Postgaming measurement, both conducted on the same day; and one Follow-Up measurement to evaluate short-term retention rate two days later.

Participants were initially instructed to perform three basic EMG assessments: the provisional maximum voluntary contraction (MVC) level, accuracy of electrode control, and muscle endurance. After a short break, participants were presented with three computer games in randomized order. After each EMG-controlled game, they were asked to complete a short user evaluation survey regarding the gaming experience. After the third and final game, a modified questionnaire aiming at intrinsic motivation (Intrinsic Motivation Inventory; IMI) was completed.

Figure 1. The experimental set-up.

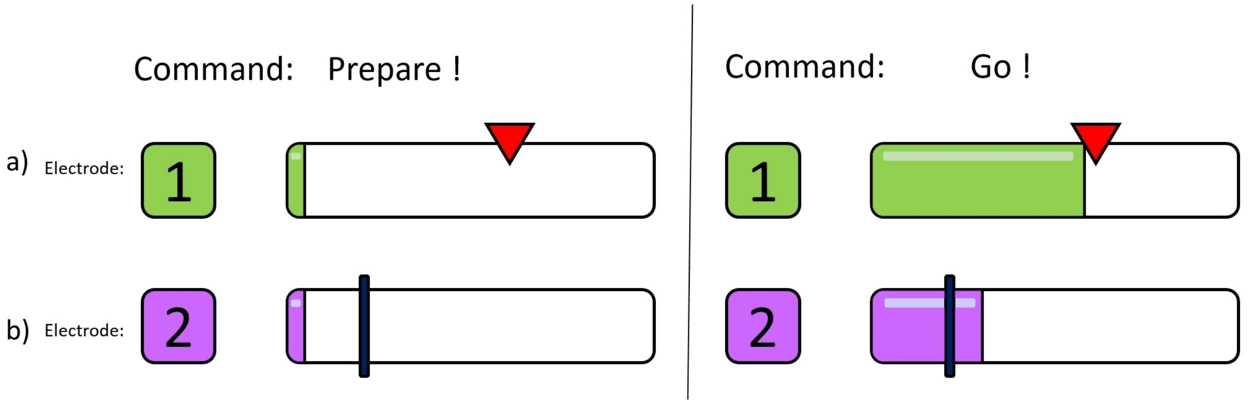


Electromyographic Assessments

To investigate the changes in overall controllability, three basic assessments evaluating approximate strength, muscle precision control and coordination, and muscle endurance were performed.

The outcome measures that were considered included fluctuations of RMS EMG signals over expected EMG signals. Both electrodes typically show some negligible offset activation (due to common noise) during the idle state of the forearm muscles (see Figure 2).

Figure 2. The interface for the precision control assessment and separation of electrode activation. Electrode 1 is used to assess precision control while electrode 2 indicates either the separation or cocontraction of both electrodes. a) The red triangle indicates the goal activation level that participants must reach with their electromyographic signals. b) The black bar marks the threshold at which the electrode is considered active. If the electromyographic signal passed this bar, electrode separation failed and cocontraction is detected.



Maximum Voluntary Contraction Test

The MVC test was used as a calibration of the voltage detected by the electrodes, and assessed the MVC force (averaged over 3 trials) for each of the two electrode channels. Participants were asked to maximally contract one muscle and to hold this contraction for 1.3 seconds, of which only the last second was taken for calculating the activation baseline.

Assessment of Precision Control

The Assessment of Precision Control test evaluated the participant's fine EMG control accuracy. The range of this test was adapted based on the outcome of the MVC test. For each electrode, the participant was asked to reach 30 randomly preselected activation levels in the range of 10-90% MVC, and sustain them for 300 milliseconds each. The required level of activation was indicated by a triangular mark on the EMG bar (see Figure 2 a). A total of 30 marks (3 trials consisting of 10 levels) were performed for each electrode. The percentile deviation from the mark was taken as outcome measure. Randomization of the goal activation marks took place once before the beginning of the study and was kept constant between all participants.

Assessment of Separation

The Assessment of Separation test is a subsection of the Assessment of Precision Control, and determined whether participants could separately control one muscle or if the opposing electrode was activated (cocontraction) during the tasks of the Precision Control assessment. Depending on the MVC, a threshold was set that corresponded to the point of EMG activation at which an electrode was considered active (see Figure 2 b). This threshold was set at 15% MVC. The concept of reaching a certain threshold for activating the electrode corresponds to the actual execution of prosthetic movements [1,25]. The outcome measure was the binary activation of the opposing electrode and the overall percentage of activation of the opposing electrode per participant.

Assessment of Endurance Control

The Assessment of Endurance Control test assessed muscle coordination and muscle fatigue while the participants used their EMG signals to closely follow a sine curve (1/4 hertz) on the screen until they felt fatigued. The estimated force needed to reach the peaks of the sine curve corresponds to 60% MVC. A positive value corresponded to activation of the first electrode, while a negative value corresponded to the second. Electrode activation needed to be separate to reach the peaks of the sine curve. The minimum time to be reached in this test was 15 minutes. The outcome measure was the EMG signal deviation from the desired sine curve, given as correlation r^2 [26].

Games

Three different open-source games were used in this study: a racing game, a dexterity game, and a rhythm-based game. Each game featured its own respective control method (see Figure 3). The general input mechanism was to substitute keyboard events with EMG activation. Participants controlled two electrodes, making two concurrent keys possible at a time. Those motions represented one degree of freedom (DoF). However, to allow for more than just one DoF steering, participants could perform a cocontraction (a quick simultaneous activation of both opposing muscles) and switch to a second DoF. For games that did not offer the option of cocontraction to switch through keys, the dominant limb supported the control through direct keyboard input.

Figure 3. An overview of the three games played by the participants, with their respective input methods and muscle contraction types needed to drive the game. EMG: electromyographic.

Game	Input Method	Player Control	Muscle Contractions
Racing Game (*SuperTuxKart*) 	EMG	Turn left, right	Quick contraction, prolonged contraction
	Non-EMG hand	Accelerating, braking	---
Rhythm Game (*Step Mania 5*) 	EMG	Activate arrows left, right	Quick contraction, prolonged contraction
	Cocontraction	Activate both arrows simultaneously	Simultaneous contraction of flexor + extensor
Dexterity Game (*Pospos*) 	EMG	Move left, right, up, down	Quick contraction, prolonged contraction
	Cocontraction	Switch control axis between left/right and up/down	Simultaneous contraction of flexor + extensor

Racing Game

In the 3-dimensional racing game *Super Tux Kart* [27] the player raced against the clock and computer-controlled adversaries. The participant controlled left and right turns solely with EMG signals, whereas accelerating and braking were controlled using keyboard inputs with their dominant hand. Required EMG activations were quick contractions and sustained contractions.

Dexterity Game

In the dexterity game *Pospos* [28] the player had to maneuver through a 2-dimensional labyrinth and collect items. This game was controlled entirely through the participant's EMG signals. Switching between the DoFs was done by cocontraction, which corresponded to controlling the horizontal and vertical axes of the player. Required EMG activations were quick contractions, sustained contractions, and cocontractions to switch between DoFs.

Rhythm Game

In the rhythm-based game *Step Mania 5* [29] participants were prompted to activate 2 different arrow-shaped buttons using their EMG signal. The arrows had to be quickly pressed or held in time matching the rhythm of the note patterns that scrolled across the screen. Required EMG activations were quick contractions, sustained contractions over a certain time period, and cocontractions to simultaneously activate two buttons.

Questionnaires

Participants were given two questionnaires to complete: (1) a modified IMI questionnaire; and (2) a user evaluation survey about the EMG assessment, the games that were played, and control methods.

Modified Intrinsic Motivation Inventory Questionnaire

A modified 28-item version of the IMI [30-32] consisting of five subscales was used to evaluate the experience with the video games that were played. The five subscales formed scores for enjoyment, perceived competence, perceived choice, pressure felt, and immersion. An additional six questions were added to the last subsection to evaluate immersion into the games. The questionnaire was adapted to the study by changing the words, "working" and, "doing" to, "playing". The questionnaire included statements such as, "I found the games very interesting" and, "I felt tense while playing." The statements were rated on a 7-point Likert rating scale ranging from 1 (*no, not at all*) to 7 (*yes, definitely*).

User Evaluation Survey

The user evaluation survey consisted of (1) rating the games that were played, (2) rating the input and player control methods (see Figure 3), (3) rating the EMG assessment, and (4) identifying engaging elements within each game. This short survey about gaming experience was presented after every game and included questions about the gameplay, fun factor, motivation, and input and control methods.

Statistical Analyses

All analyses were conducted using IBM SPSS 20 and Matlab 2013b. Nonparametric tests were performed on data not meeting the requirement for normal distributions. Normal distributions were assessed via graphical interpretation showing normal Q-Q plots, and with Shapiro-Wilk tests for normality as a numerical assessment. Significance was set at Cronbach alpha=.05.

Controllability

Maximum Voluntary Contraction

This test was used to relatively set the maximum contraction limit for the subsequent EMG tests, and was given as average of the RMS electrode activation. MVC was measured three times: before playing the games, directly after playing the games, and before the Follow-Up measurement.

Assessment of Precision Control

The outcome measure for this test was the percent deviation from the 30 goal points per electrode channel. The deviation from the goal was calculated in absolute values and set in relation to the achieved MVC to derive a percent value of deviation for each goal point. All 30 data points were treated as if they were performed consecutively. The goal points were divided into three equidistant intensity sections ranging from 10% MVC to 90% MVC. The Shapiro-Wilk test confirmed a normal distribution with $P<.001$. The mean and standard deviation were compared for significance for the activation levels (low, middle, high) and for measurement sessions (Pregaming, Postgaming, Follow-Up) with a Bonferroni corrected paired samples t-test.

Assessment of Separation

Threshold crossings were given in percentages for each of the 3 goal activation levels over the 3 measurement sessions. The three equidistant intensity levels ranged from 10-90%. Improvement was tested for significance with a related samples Wilcoxon signed rank test.

Assessment of Endurance Control

The conformity of retracing the sine curve as a correlation r^2 was computed for defined time windows consisting of 30 seconds. The highest r^2 value was taken from a period of at least 200 seconds. A related samples Wilcoxon signed rank test (Cronbach alpha=.05) examined the Pregaming measurement correlation with the Follow-Up measurement correlation.

Questionnaires

Intrinsic Motivation Inventory Questionnaire

Participants had to rank the 28 statements from 1 to 7, where 1 represented *I do not agree* and 7 represented *I agree*. The statements belonged to one of five categories and the ranking was averaged. An independent samples Mann Whitney U test was performed to describe the data. All categories except *pressure* had a high desirable rank.

User Evaluation Survey

This survey consisted of ranked statements on a 5-point scale, and multiple choice questions regarding game experience and preferences that were evaluated via a frequency analysis.

Results

Controllability

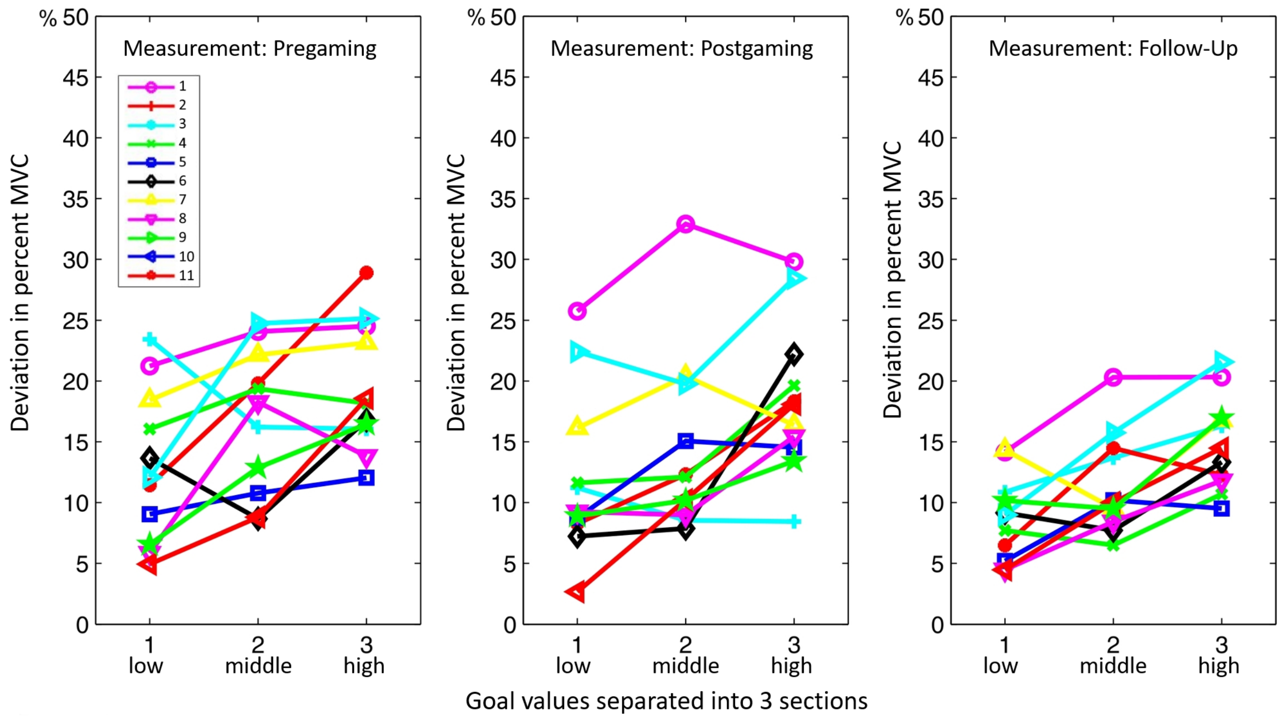
Maximum Voluntary Contraction

The MVC was used only as a calibration for the electrode channel voltage. However, it could be observed that the RMS values for the MVC test directly after the games showed an increase instead of the expected decrease. Moreover, the same can be observed for the Follow-Up session.

Assessment of Precision Control

Results showed a significant improvement in fine accuracy and electrode coordination from the Pregaming measurement to the Follow-Up session (P=.001). Percentile deviation from the goal value was high and heterogeneous in the first two measurements (Pregaming and Postgaming), but significantly lower and more homogeneous in the Follow-Up measurement (P=.001; see Figure 4). In all 3 measurement sessions, it was significantly harder to reach a high goal activation level compared to a low one (P=.002).

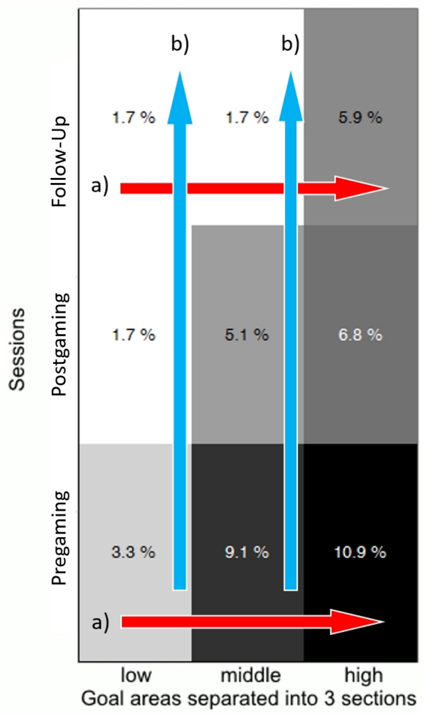
Figure 4. Development of the deviation of the electrode activation around the goal value levels (separated into low, middle, and high goal values) through all three measurement sessions (Pregaming, Postgaming and Follow-Up). MVC: maximum voluntary contraction.



Assessment of Separation

Significantly better performance could be observed during low level electrode activation tasks compared to high goal activation tasks within Pregaming (*P*=.02) and the Follow-Up session (*P*=.04; see Figure 5 a). There was a significant decrease in opposing electrode activation from the first to the last measurement session for low (*P*=.04) and middle (*P*=.02) goal activation levels; however, this was not true for high intensity goal activation (see Figure 5 b). There was a significant improvement in electrode separation overall, considering the first and last measurement sessions (*P*=.02).

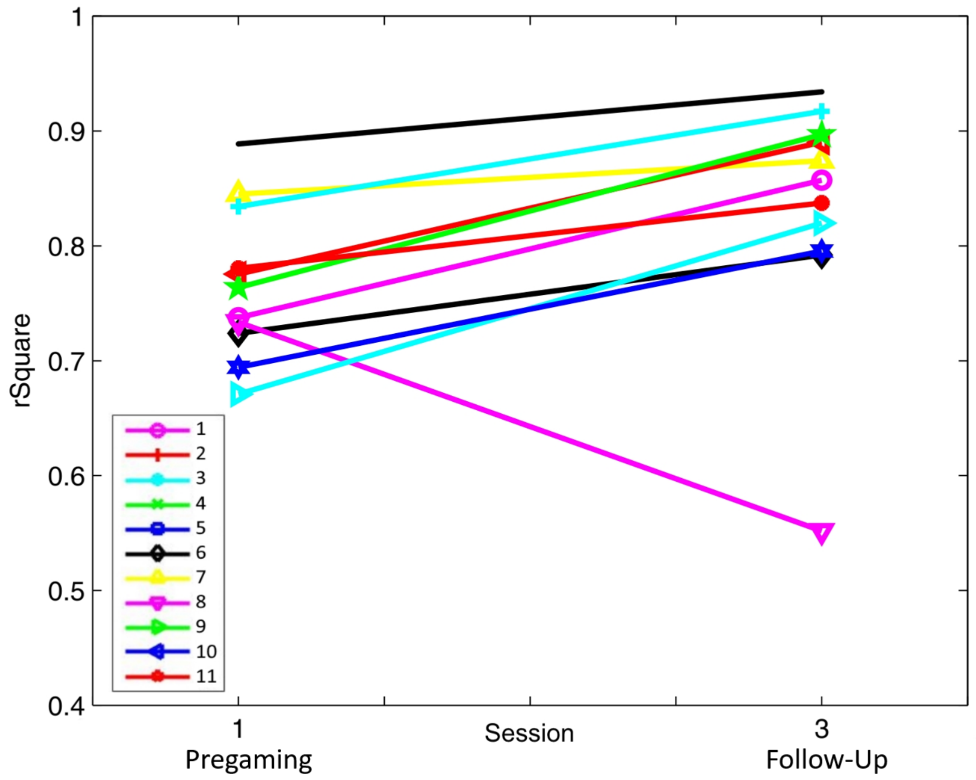
Figure 5. Opposing electrode activations over three measurement sessions (Pregaming, Postgaming and Follow-Up) and three goal activation areas, which the participants had to reach with their electromyographic signal (low, middle, and high). a) Comparison within the session. b) Comparison between the sessions.



Assessment of Endurance Control

Participants showed an improvement in muscle endurance control (see Figure 6). This result was true for all but one participant, whose EMG activation expressed an offset and was shifted by half a period of the retraced sine curve. Nevertheless, the Related Samples Wilcoxon Signed Rank Test determined a significant difference (P=.004) in r^2 performance between the Pregaming and Follow-Up measurement sessions.

Figure 6. Scores of the endurance assessment and comparison of Pregaming r^2 value to the Follow-Up value. High r^2 corresponds to close electromyographic retracing of the given sine curve.



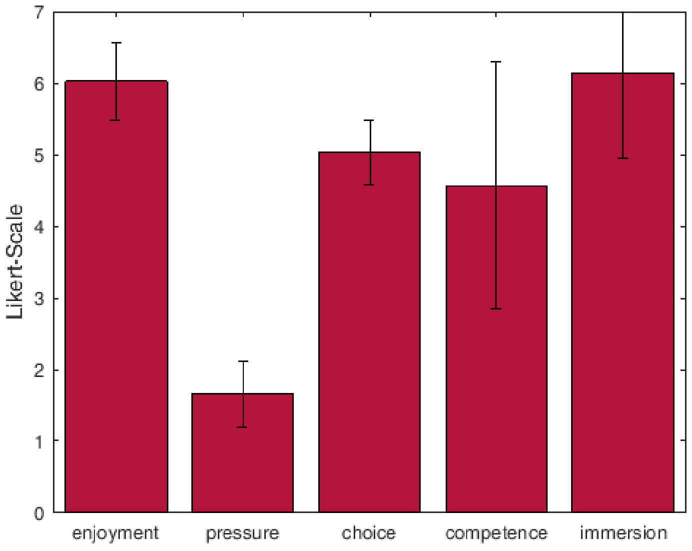
Questionnaires

Modified Intrinsic Motivation Inventory

Results obtained from the IMI questionnaire can be viewed as mean and standard deviation of the five categories in Figure 7.

Participants enjoyed playing the games and felt immersed when doing so. Participants perceived playing the games as their own choice and felt competent and at ease while doing so. *Pressure* was the only category in which a low rank was desirable.

Figure 7. Means and standard deviations for 5 subscales of the modified intrinsic motivation questionnaire on a scale from 1 (low) to 7 (high).



User Evaluation Survey

Participants were asked to answer five questions for each game (Q1-Q5; see Figure 8). According to the user evaluation survey, the favorite game (derived from the score of Q1 and Q2) was the racing game *Super Tux Cart* followed by the rhythm game *Step Mania 5*. According to Q3 and Q4, participants preferred to control the games with EMG signals only and to perform different contraction lengths as well as cocontractions. In terms of motivation (Q5), the *Pospos* dexterity game ranked far behind the racing and rhythm games, which were equally well received.

The most important components to ensure continued play and enjoyment of a game were (listed according to importance): (1) the EMG control method, (2) the level of difficulty, (3) dynamic movements, and (4) collecting items. Music, atmosphere, and graphics rated last. Although participants claimed to prefer 3-dimensional graphics, this finding did not reflect their rating of what they enjoyed most in the games. The most motivating aspects of games were (1) the gameplay, (2) to see one's own high score, and (3) to clear upgrades.

Additionally, participants had to rate the EMG assessments after each session. Participants were asked about how important they thought the EMG assessments were, and to rate the fun they had while doing them. As can be seen in Figure 9, rating of the importance of the EMG assessment increased until the Follow-Up measurement (however, not significantly), while the participants enjoyed them significantly less (P=.002). Interestingly, a slight rise in rating the fun factor was observed after the Follow-Up session.

Figure 8. Mean and standard deviation ratings of the three games played, according to the survey that participants had to fill in after each game.

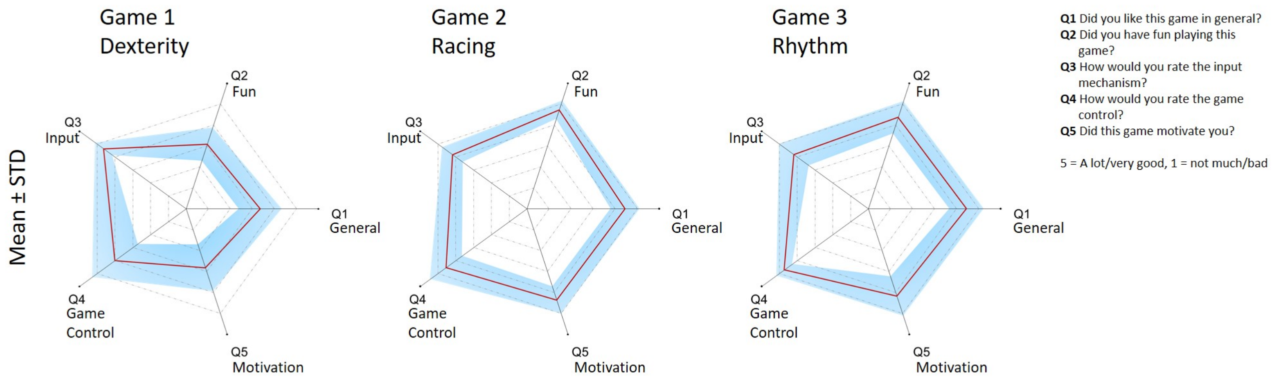
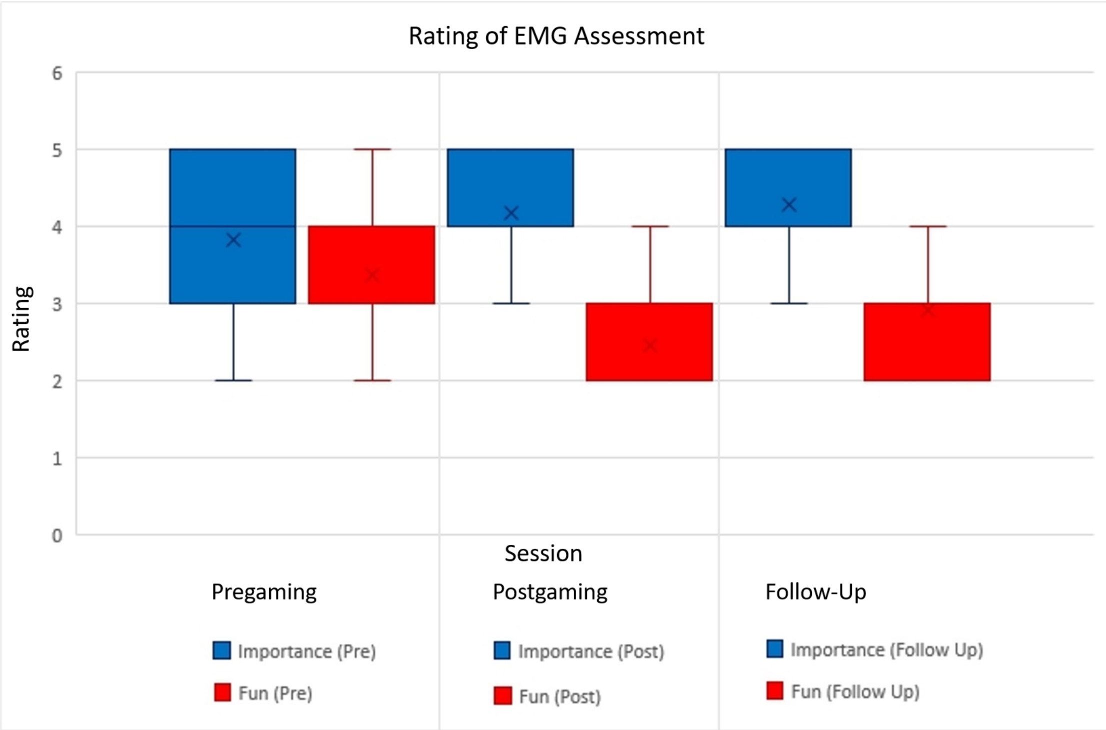


Figure 9. Mean and standard deviation for ratings of the electromyographic assessment after each session, ranging from 5 (very important/fun) to 1 (very unimportant/boring). EMG: electromyographic.



Discussion

Results from this study demonstrate improvements in fine accuracy electrode activation and electrode separation from Pregaming EMG assessments to the Follow-Up measurements. Surprisingly, the MVC values used as a baseline calibration also showed an increase, instead of the expected decrease, after playing the games. This result could be due to either warmth or sweat that would influence the electrode resistance. Additionally, this result is a strong indicator that the gaming session was not fatiguing for the participants. Performance during the precision control assessment, however, declined after playing the games. If, based on previous investigations, we exclude fatigue, it is reasonable to assume that participants started losing their concentration by the end of the sessions. In the Follow-Up measurement, a clear improvement in performance was observed, which can be attributed to the restoration of full focus combined with the obtained experience from the previous session.

Compared to previous studies [22-24,33], participants not only conducted repetitive flexor and extensor muscle activation, but also sustained contractions over varying periods of time, performed precisely timed contractions, and executed simultaneous contractions of both muscle groups. These actions are similar to how patients would control a real prosthesis.

The motivational aspects of training gamification are clear, and are likely the main advantage compared to conventional techniques. It is reasonable to assume that certain improvement of the EMG control could be observed by sole application of the listed EMG tests. However, prolonged exposure to such stimuli would certainly lead to a loss of interest, which is sure to be maintained by the appealing context of a video game [15].

Limitations

The transferability of the obtained results to the amputee population might be questioned, since this study was conducted strictly with healthy participants. However, based on the outcomes reported in other myocontrol-based studies [34,35], it is reasonable to expect that the patient group would perform similarly.

This study was a short-term intervention, and can be viewed as a proof of concept. Further research will incorporate a long-term evaluation of video game-based interventions, as well as additional exploration of advanced control mechanisms, such as those based on machine learning approaches [36-38].

Conclusion

Most upper limb amputees use a 2-channel myoelectric prosthesis control. This study demonstrates that this control can be effectively trained by employing a video game-based rehabilitation protocol. Participants significantly improved their electrode separation and fine muscle control. It could be shown that the enjoyment of the games was greater than that of the EMG assessments, which decreased over time. Additionally, engaging elements within each game could be identified. A subsequent study with an amputee population will show if the information gained from healthy participants can be transferred to patients. The final outcome would be a robust system that patients can operate outside of a clinical environment.

Acknowledgments

This work was supported by the Christian Doppler Research Foundation of the Austrian Federal Ministry of Science, Research and Economy, and by the European Research Council Advanced Grant DEMOVE (contract #267888). The authors would like to thank Korbinian Eckstein, MSc for system implementations. Authors CP and IV designed and conducted the study, led the analysis, and interpreted the data; all authors contributed to drafting and reviewing the manuscript.

Conflicts of Interest

None declared.

References

1. Roche AD, Rehbaum H, Farina D, Aszmann OC. Prosthetic myoelectric control strategies: a clinical perspective. Curr Surg Rep 2014 Jan 25;2(3). [doi: 10.1007/s40137-013-0044-8]
2. Sturma A, Göbel P, Herceg M, Gee N, Roche A, Fialka-Moser V, et al. Advanced rehabilitation for amputees after selective nerve transfers: EMG-guided training and testing. In: Replace, Repair, Restore, Relieve – Bridging Clinical and Engineering Solutions in Neurorehabilitation. New York: Springer; 2014:169-177.
3. Kyberd PJ, Beard DJ, Davey JJ, Morrison JD. A survey of upper-limb prosthesis users in Oxfordshire. JPO 1998;10(4):84-91. [doi: 10.1097/00008526-199801040-00004]
4. Dudkiewicz I, Gabrielov R, Seiv-Ner I, Zelig G, Heim M. Evaluation of prosthetic usage in upper limb amputees. Disabil Rehabil 2004 Jan 7;26(1):60-63. [doi: 10.1080/09638280410001645094] [Medline: 14660200]
5. Weeks DL, Anderson DI, Wallace SA. The role of variability in practice structure when learning to use an upper-extremity prosthesis. JPO 2003;15(3):84-92. [doi: 10.1097/00008526-200307000-00006]
6. Roche AD, Vujaklija I, Amsüss S, Sturma A, Göbel P, Farina D, et al. A structured rehabilitation protocol for improved multifunctional prosthetic control: a case study. J Vis Exp 2015 Nov 06(105):e52968. [doi: 10.3791/52968] [Medline: 26575620]
7. Smurr LM, Gulick K, Yancosek K, Ganz O. Managing the upper extremity amputee: a protocol for success. J Hand Ther 2008 Apr;21(2):160-75; quiz 176. [doi: 10.1197/j.jht.2007.09.006] [Medline: 18436138]
8. Aszmann OC, Roche AD, Salminger S, Paternostro-Sluga T, Herceg M, Sturma A, et al. Bionic reconstruction to restore hand function after brachial plexus injury: a case series of three patients. The Lancet 2015 May;385(9983):2183-2189. [doi: 10.1016/s0140-6736(14)61776-1]
9. Anderson F, Bischof W. Augmented reality improves myoelectric prosthesis training. Int J Disabil Hum Dev 2014;13(3):349-354. [doi: 10.1515/ijdhd-2014-0327]
10. Dawson MR, Carey JP, Fahimi F. Myoelectric training systems. Expert Rev Med Devices 2011 Sep;8(5):581-589. [doi: 10.1586/erd.11.23] [Medline: 22026623]
11. Kotila M, Numminen H, Waltimo O, Kaste M. Depression after stroke: results of the FINNSTROKE Study. Stroke 1998 Feb;29(2):368-372 [FREE Full text] [Medline: 9472876]
12. Burke JW, McNeill MDJ, Charles DK, Morrow PJ, Crosbie JH, McDonough SM. Optimising engagement for stroke rehabilitation using serious games. Vis Comput 2009 Aug 27;25(12):1085-1099. [doi: 10.1007/s00371-009-0387-4]
13. Tatla SK, Shirzad N, Lohse KR, Virji-Babul N, Hoens AM, Holsti L, et al. Therapists' perceptions of social media and video game technologies in upper limb rehabilitation. JMIR Serious Games 2015;3(1):e2 [FREE Full text] [doi: 10.2196/games.3401] [Medline: 25759148]
14. Armiger R, Vogelstein R. Air-Guitar Hero: a real-time video game interface for training and evaluation of dexterous upper-extremity neuroprosthetic control algorithms. In: Biomedical Circuits and Systems Conference. 2008 Presented at: BioCAS; Nov 2008; IEEE p. 121-124. [doi: 10.1109/biocas.2008.4696889]
15. Lohse K, Shirzad N, Verster A, Hodges N, Van der Loos HF. Video games and rehabilitation: using design principles to enhance engagement in physical therapy. J Neurol Phys Ther 2013 Dec;37(4):166-175. [doi: 10.1097/NPT.0000000000000017] [Medline: 24232363]
16. van Diest M, Stegenga J, Wörtche HJ, Verkerke GJ, Postema K, Lamoth CJ. Exergames for unsupervised balance training at home: a pilot study in healthy older adults. Gait Posture 2016 Feb;44:161-167. [doi: 10.1016/j.gaitpost.2015.11.019] [Medline: 27004651]
17. Duncan PW, Horner RD, Reker DM, Samsa GP, Hoenig H, Hamilton B, et al. Adherence to postacute rehabilitation guidelines is associated with functional recovery in stroke. Stroke 2002 Jan;33(1):167-177 [FREE Full text] [Medline: 11779907]
18. Lang CE, Macdonald JR, Reisman DS, Boyd L, Jacobson KT, Schindler-Ivens SM, et al. Observation of amounts of movement practice provided during stroke rehabilitation. Arch Phys Med Rehabil 2009 Oct;90(10):1692-1698 [FREE Full text] [doi: 10.1016/j.apmr.2009.04.005] [Medline: 19801058]
19. Gil-Gómez J, Lloréns R, Alcañiz M, Colomer C. Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. J Neuroeng Rehabil 2011;8:30 [FREE Full text] [doi: 10.1186/1743-0003-8-30] [Medline: 21600066]

20. Herz NB, Mehta SH, Sethi KD, Jackson P, Hall P, Morgan JC. Nintendo Wii rehabilitation ("Wii-hab") provides benefits in Parkinson's disease. Parkinsonism Relat Disord 2013 Nov;19(11):1039-1042. [doi: 10.1016/j.parkreldis.2013.07.014] [Medline: 23968649]
21. Al-Jumaily A, Olivares R. Electromyogram (EMG) driven system based virtual reality for prosthetic and rehabilitation devices. 2009 Presented at: Proceedings of the 11th International Conference on Information Integration and Web-based Applications & Services; December 14-16, 2009; New York p. 582-586. [doi: 10.1145/1806338.1806448]
22. Oppenheim H, Armiger R, Vogelstein R. WiiEMG: a real-time environment for control of the Wii with surface electromyography. 2010 Presented at: Proceedings of 2010 IEEE International Symposium on Circuits and Systems (ISCAS); May 30-June 2, 2010; Paris, France p. 957-960. [doi: 10.1109/iscas.2010.5537390]
23. de la Rosa R, Alonso A, de la Rosa S, Abasalo D. Myo-Pong: a neuromuscular game for the UVa-Neuromuscular Training System platform. 2008 Presented at: Virtual Rehabilitation ICVR; August 25-27, 2008; Vancouver, BC p. 61-61. [doi: 10.1109/icvr.2008.4625124]
24. Bouwsema H, van der Sluis CK, Bongers RM. The role of order of practice in learning to handle an upper-limb prosthesis. Arch Phys Med Rehabil 2008 Sep;89(9):1759-1764. [doi: 10.1016/j.apmr.2007.12.046] [Medline: 18675393]
25. Sturma A, Herceg M, Bischof B, Fialka-Moser V, Oskar A. Rehabilitation following targeted muscle reinnervation in amputees. In: Replace, Repair, Restore, Relieve--Bridging Clinical and Engineering Solutions in Neurorehabilitation. New York: Springer; 2014:775-779.
26. d'Avella A, Portone A, Fernandez L, Lacquaniti F. Control of fast-reaching movements by muscle synergy combinations. J Neurosci 2006 Jul 26;26(30):7791-7810 [FREE Full text] [doi: 10.1523/JNEUROSCI.0830-06.2006] [Medline: 16870725]
27. Henrichs J, Gagnon M, Hernandez Munoz E, Baker S. SuperTuxKart. 2015. URL: https://supertuxkart.net/Main_Page [accessed 2017-01-23] [WebCite Cache ID 6njJWpdEv]
28. Gramatke S, Gramatke C. Heise. 2015. Pospos - Im Land der Chukchuks URL: https://www.heise.de/download/product/pospos-im-land-der-chuchuks-74513 [accessed 2017-01-18] [WebCite Cache ID 6nbplEWfs]
29. Danford C, Maynard G. Step Mania 5. 2015. URL: https://www.stepmania.com/download/ [accessed 2017-01-18] [WebCite Cache ID 6nbpCoYec]
30. Ryan RM. Control and information in the intrapersonal sphere: an extension of cognitive evaluation theory. J Pers Soc Psychol 1982;43(3):450-461. [doi: 10.1037//0022-3514.43.3.450]
31. von Held F. Collective Creativity: Exploring Creativity in Social Network Development as Part of Organizational Learning. Wiesbaden: VS Verlag fuer Sozialwissenschaften; 2012.
32. McAuley E, Duncan T, Tammen VV. Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: a confirmatory factor analysis. Res Q Exerc Sport 1989 Mar;60(1):48-58. [doi: 10.1080/02701367.1989.10607413] [Medline: 2489825]
33. Terlaak B, Bouwsema H, van der Sluis CK, Bongers RM. Virtual training of the myosignal. PLoS One 2015 Sep;10(9):e0137161 [FREE Full text] [doi: 10.1371/journal.pone.0137161] [Medline: 26351838]
34. Wurth SM, Hargrove LJ. A real-time comparison between direct control, sequential pattern recognition control and simultaneous pattern recognition control using a Fitts' law style assessment procedure. J Neuroeng Rehabil 2014 May 30;11:91 [FREE Full text] [doi: 10.1186/1743-0003-11-91] [Medline: 24886664]
35. Farina D, Jiang N, Rehbaum H, Holobar A, Graimann B, Dietl H, et al. The extraction of neural information from the surface EMG for the control of upper-limb prostheses: emerging avenues and challenges. IEEE Trans Neural Syst Rehabil Eng 2014 Jul;22(4):797-809. [doi: 10.1109/TNSRE.2014.2305111] [Medline: 24760934]
36. Prahm C, Eckstein K, Ortiz-Catalan M, Dorffner G, Kaniusas E, Aszmann OC. Combining two open source tools for neural computation (BioPatRec and Netlab) improves movement classification for prosthetic control. BMC Res Notes 2016 Aug 31;9(1):429 [FREE Full text] [doi: 10.1186/s13104-016-2232-y] [Medline: 27581624]
37. Jiang N, Dosen S, Muller K, Farina D. Myoelectric control of artificial limbs - is there a need to change focus? [in the spotlight]. IEEE Signal Process Mag 2012 Sep;29(5):152-150. [doi: 10.1109/MSP.2012.2203480]
38. Amsuess S, Vujaklija I, Goebel P, Roche AD, Graimann B, Aszmann OC, et al. Context-dependent upper limb prosthesis control for natural and robust use. IEEE Trans Neural Syst Rehabil Eng 2016 Jul;24(7):744-753. [doi: 10.1109/TNSRE.2015.2454240] [Medline: 26173217]

Abbreviations

DoF: degree of freedom
EMG: electromyographic
IMI: Intrinsic Motivation Inventory
MVC: maximum voluntary contraction
RMS: root mean square

Edited by G Eysenbach; submitted 25.05.16; peer-reviewed by S Flynn, R Armiger, F Anderson; comments to author 28.06.16; revised version received 18.11.16; accepted 06.01.17; published 09.02.17.

Please cite as:
Prahm C, Vujaklija I, Kayali F, Purgathofer P, Aszmann OC
Game-Based Rehabilitation for Myoelectric Prosthesis Control
JMIR Serious Games 2017;5(1):e3
URL: https://games.jmir.org/2017/1/e3/
doi:10.2196/games.6026
PMID:28183689

Original Paper

A Mobile, Avatar-Based App for Improving Body Perceptions Among Adolescents: A Pilot Test

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Abstract

Background: One barrier to effectively treating weight issues among adolescents is that they tend to use social comparison instead of objective measures to evaluate their own health status. When adolescents correctly perceive themselves as overweight, they are more likely to adopt healthy lifestyle behaviors.

Objective: The purpose of this pilot test was to develop and assess acceptability and usability of an avatar-based, theoretically derived mobile app entitled Monitor Your Avatar (MYA).

Methods: The MYA app was engineered for high school adolescents to identify, using avatars, what they thought they looked like, what they wanted to look like, and what they actually looked like based on body measurements.

Results: The MYA app was pilot-tested with male and female adolescents aged 15-18 years to assess for acceptability and usability. A total of 42 students created and viewed their avatars. The majority of the adolescents were female (28/42, 67%), age 16 years (16/42, 38%), white (35/42, 83%), non-Hispanic (36/42, 86%), in grade 10 (20/42, 48%), healthy weight for females (23/28, 82%), and obese for males (7/14, 50%). The adolescents had positive reactions to the avatar app and being able to view avatars that represented them. All but one student (41/42, 98%) indicated some level of comfort viewing the avatars and would use the app in the future to see how their bodies change over time.

Conclusions: Avatar-based mobile apps, such as the MYA app, provide immediate feedback and allow users to engage with images that are personalized to represent their perceptions and actual body images. This pilot study adds to the increasing but limited research of using games to improve health outcomes among high school adolescents. There is a need to further adapt the MYA app and gather feedback from a larger number of high school adolescents, including those from diverse backgrounds.

(JMIR Serious Games 2017;5(1):e4) doi:10.2196/games.6354

KEYWORDS

adolescents; avatars; eHealth; mHealth; perceptions; Web-based; usability testing

Introduction

One in five adolescents in the United States are obese, increasing their risk for related complications such as poor quality of life, asthma, type 2 diabetes, and hypertension. Additionally, as they age, adolescents' participation in physical activity decreases [1], while concern about weight and negative body image increases [2].

One barrier to treating these adolescent weight issues is that they tend to use social comparison instead of objective measures to evaluate their own health status [3]. Having inaccurate body size perceptions may decrease adolescents' likelihood of changing their health behaviors [4]. If adolescents correctly perceive themselves as overweight, they are more likely to adopt healthy lifestyle behaviors [5] than will those who do not recognize themselves as overweight [4].

Another barrier to effectively treating weight issues among adolescents is misclassifying obesity risk due to incomplete measures for adolescents. Researchers and health care providers have long used body mass index (BMI), a common, inexpensive measure, to determine healthy weight in adolescents. BMI does not distinguish between fat and muscle, does not identify body size perceptions, and cannot detect those at risk for unnecessary and unsafe weight loss behaviors. There is a potential for adolescents to not receive appropriate counseling and referral if their body fat percentage, perceptions, and methods for losing weight are not assessed along with BMI [6].

Adolescents also contend with using the current methods to assess healthy body sizes. Using BMI may be too vague or abstract for adolescents to comprehend. Their weight in pounds on a scale may change insignificantly or not at all even though positive lifestyle changes are substantial. Choosing from a series of body figure silhouettes may not be true representations of the adolescents' body shapes. These methods of assessing body weight classifications and changes made to the bodies may prevent adolescents from seeing the effects that healthy eating and physical activity can have on their health.

As children move into adolescence, they are more likely to desire independence in attaining and maintaining healthy bodies. Identification (ie, the extent an individual relates to a model and feels similarity to the model) can increase the likelihood for a teen to perform a learned behavior [3,7]. The power of identification increases when the models are of the same sex [4], race [5], or skill level [6]. Fox and Bailenson [8] conducted three studies and found virtual self-models can be an effective impetus for health behavior change. Virtual self-models such as avatars (ie, computerized representations of the adolescents' bodies) can be connected to goal setting, self-monitoring, direct reinforcement, and social support processes that drive behavior change. Having adolescents interact with avatars on mobile devices, such as tablet computers, engages them in viewing and thinking about their bodies in a realistic and positive light.

Visually rich 3D representations that accurately portray how bodies appear may have a greater impact on adolescent behavior than can a number on a scale or BMI percentage. In addition, adolescents prefer Internet-based health resources because of the 24-hour availability and lack of perceived judgment and conflict with sensitive topics [9]. Mobile phone technology has the ability to track everyday behavior changes in an unobtrusive way, in real time [10,11], and with the potential to provide immediate feedback [12].

Researchers and providers can have a greater impact on adolescents' actions to change their bodies or help maintain healthy bodies by providing interactive and dynamic strategies. Further, over 93% of teens are active users of the Internet [13], 75% own mobile phones [14], and 40% own iPhones [15], suggesting that Web- and mobile device-based apps can be powerful technologies for implementing behavior change programs in this population.

The purpose of this pilot test was to develop and assess acceptability and usability of an avatar-based, theoretically derived, mobile app entitled *Monitor Your Avatar* (MYA). Positive lifestyle changes can affect adolescents' body composition, which in turn can affect their perceptions of their bodies, their body shapes, their satisfaction with their bodies, and their emotional well-being as they mature into adulthood.

Methods

Design and Development of the App

The MYA app was engineered for male and female high school adolescents to identify, using avatars, what they thought they looked like, what they wanted to look like, and what they actually looked like based on body measurements. The MYA app is interactive and designed for adolescents to change specific body parts of the avatars; they can also access the app recurrently to help monitor their targeted goals. The completion of the app consisted of three phases: classification, development, and prototype testing. The three phases of the project were derived from combining a model-driven approach to developing software [16] along with an iterative user-centered design approach to creating mobile health apps [17]. The classification phase required the collection of accurate datasets, the development phase developed the models based on this data, and the prototype-testing phases incorporated user testing to validate the models developed in the previous stage. All policies, procedures, and ethical concerns for all phases were approved by the Institutional Review Board of the university and high school. All parents provided informed consent and all adolescents provided assent to participate.

Classification Based on Body Scans

The purpose of the classification phase was to classify the models based on body scans for use when creating the three avatars.

Procedure for Body Scans

In order to develop a classification, it was necessary to body-scan male and female adolescents 15-18 years of age. Regarding recruitment, subject inclusion criteria were as follows: (1) in grades 9-12; (2) able to speak, read, and write English; (3) able to stand on a turntable for the 1-minute body scan; and (4) comfortable wearing form-fitting clothes such as compression shorts, leggings, form-fitting tank top, or swimwear. MyBodee by Styku [15] was used to scan the adolescents. MyBodee [15] is a portable and highly accurate body measurement technology. The adolescents wore form-fitting clothes and stood on a turntable. Using a tablet and 3D camera, the researcher measured each adolescent's full body shape. The adolescent slowly spun a full 360 degrees on a safe and automated turntable. After 40 seconds, the adolescent's scan was sent to a secure, private network where the research team concurrently analyzed the shape and body measurements. The research team also collected additional body measurements, including the widths and circumferences of the chest, biceps, waist, hips, thigh, and calf using a body tape measure. The scan did not measure the widths of these body parts, so collection of the circumferences and widths of the body parts was needed to configure ratios to be used during the classification phase. A total of 47 adolescents 15-18 years of age were scanned—24 male and 23 female—using MyBodee [15]. MyBodee [15] was only needed to scan the adolescents so their body scans could be used to classify the models for use in the app.

Classification

Before creating the models, the research team classified the scanned models using the ratio of height and weight. According to the ratio, we classified both male and female models into six groups. In each group, we selected one or two of the most representative models and reviewed their measurements. The measurements included height and weight as well as the widths and circumferences of the chest (breast/bust), waist, hips, biceps, thigh, and calf. These measurements were used to create baseline models for the app using the MakeHuman software (MakeHuman) [18].

Development of the Monitor Your Avatar App Avatars

Overview

The purpose of the development phase was to use the classified models and build a pipeline to display and manipulate them via a Web app. The Web app called MYA provides an interface (see Figure 1) for the participants to engage with the following avatars: *Perceived Avatar* (what adolescents think they look like), *Target Avatar* (what adolescents want to look like), and the *Actual Avatar* (what adolescents actually look like based on body measurements).

Procedure for Prototype Development

The prototype development consisted of three steps: (1) Modeling: generating the baseline models using MakeHuman [18]; (2) Display: rendering the models via a Web interface written in JavaScript and WebGL [19]; and (3) Analysis: saving the user-generated avatar content to a secure database for research and analysis.

Modeling

With the provided measurements, the models were created by setting up the gender, height, and age in MakeHuman [18]. The scanned model and measurements were used as a reference to match the body type and create the baseline model that is geometrically similar to the scanned model. MakeHuman models are not fragmented into body parts and manipulating one area had no effect on the other. Since we were seeking local control and manipulation based on measurements of specific body parts, we had to use the Blender 3D software (Blender) [20] to fragment the model into body parts. A new model whose individual body parts could be manipulated by varying the measurements using sliders was created. With this model, the slider could be used to manipulate each body part independently and provide the ability to export the functionality to the Web.

Display

The models from the Blender software were exported as a single JSON file [21] that contained the location and name of all the baseline models. Once a representative sample was selected based on height, weight, and gender input we used Three.js [22], a Web-based, 3D-rendering application programming interface, for loading and displaying the appropriate baseline model with the manipulating sliders. The manipulation of the body parts is done independently by an algorithm that morphs the 3D object based on predetermined minimum and maximum 3D surfaces for each body part. The *Actual Avatar* is generated by having the users input the body measurements and algorithmically calculate the morph targets for this input set.

Analysis

When the user completed the three avatars, the measurements of all body parts for all the avatars were retrieved and the WebGL content was saved into an image format. The measurements of body parts were saved onto a spreadsheet. All three avatars were compiled onto a screen capture and the final state of the app was saved. A server-side script was written to give administrative access to the research team to easily download this data for all the adolescents.

Prototype Testing of the Monitor Your Avatar App

Overview

The purpose of the third phase was to determine the acceptability and usability of the MYA app in male and female adolescents aged 15-18 years. Acceptability was defined as thoughts on viewing the avatars and visual representation, as well as comfort level of using, intent to use, and satisfaction with the app. Usability was defined as ease of using and actual use the app, need to look for help when using the app, understanding of how to use the app, and engagement of the app.

Procedure for Prototype Testing

Participant inclusion criteria included the following: (1) in grades 9-12; (2) able to speak, read, and write English; (3) has not been diagnosed with an eating disorder or depression, as provided by a school nurse; and (4) be comfortable wearing form-fitting clothes such as compression shorts, leggings, form-fitting tank top, or swimwear for taking measurements. These adolescents were not part of the body scan study completed for the classification phase. The research team introduced the study to 45 adolescents in two high school physical education classes. One adolescent elected not to be part of the study and two others were absent on the day of data collection.

During data collection, the adolescents wore form-fitting clothes. The research team measured the height of the adolescents using a stadiometer and their weight and body fat percentage using a Tanita body composition analyzer. We also measured the adolescents' body parts—biceps, chest/bust, waist, hips, thigh, and calf—using a body tape measure to obtain circumferences. The girls also had their bust girth measured, in addition to their chest/bust, for entry into the *Actual Avatar* feature.

After measurement, the adolescents entered an assigned identification number, their gender, measured weight, and measured height into the app to populate a baseline avatar using the computer located in the school library. They then designed the avatar to represent how they currently perceive their bodies to look (*Perceived Avatar*). The app allowed each adolescent to make the body parts (ie, biceps, chest/bust, bust girth, waist, hips, thighs, and calves) bigger or smaller using the slider. Their completed *Perceived Avatar* then generated on the same screen so they could design it to represent how they wanted their bodies to look within realistic, healthy parameters (*Target Avatar*). This feature was incorporated so the adolescents could work from their current perception rather than having to start over. On the same screen and to the right of the *Perceived* and *Target Avatars*, the adolescents generated an *Actual Avatar* by entering their body part measurements into the app. Figure 2 displays the three avatars after completion. The avatars could be rotated 360 degrees. Figure 3 displays the three avatars from the side view.

The adolescents were then asked to answer questions about their reactions to creating and viewing the avatars to assess acceptability and to complete the Software Usability Survey. The open-ended reaction questions posed to the adolescents included the following: "What do you think about being able to view avatars of yourself?" "Do you think the avatars are a good representation of yourself? Explain why or why not." "How comfortable were you creating and viewing your avatars?" "In the future, would you use these avatars to see how your body parts are changing? Explain why or why not." "What do you like about the avatars?" "What do you not like about the avatars?" "What would you change about the avatars?"

The Software Usability Survey is a short usability 7-point Likert-type scale survey informed by the product and best practices in software engineering [23,24]. The items used to identify usability for the MYA app included the following: (1) simplicity of navigation from one page to another, (2) ease of control to view the avatars and their body parts, (3) ease to manipulate each body part and make it look more muscular, (4) need to look for help when working with the app, (5) understanding of what the three avatars are and how to view and manipulate them, (6) ability to keep the user engaged and not quit, and (7) overall satisfaction with ease of using the app.

Figure 1. User Interaction Screens for MYA App.

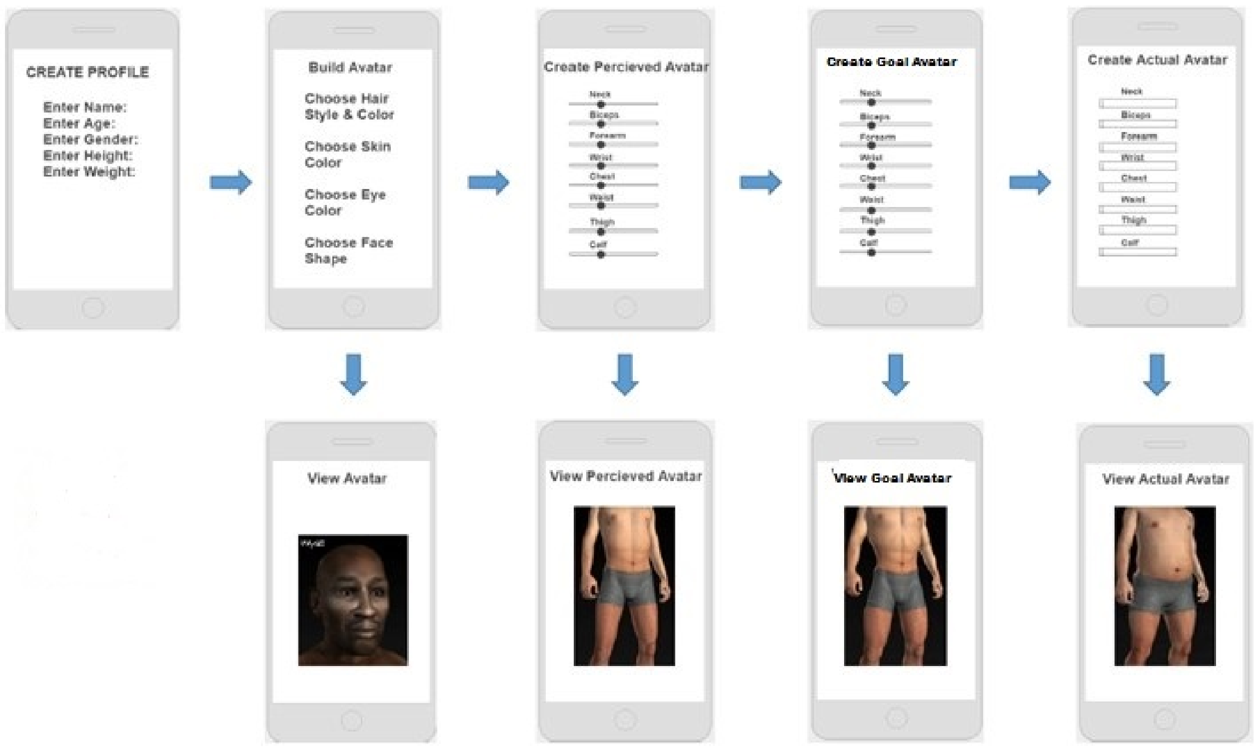


Figure 2. Example of three female avatars (front view).

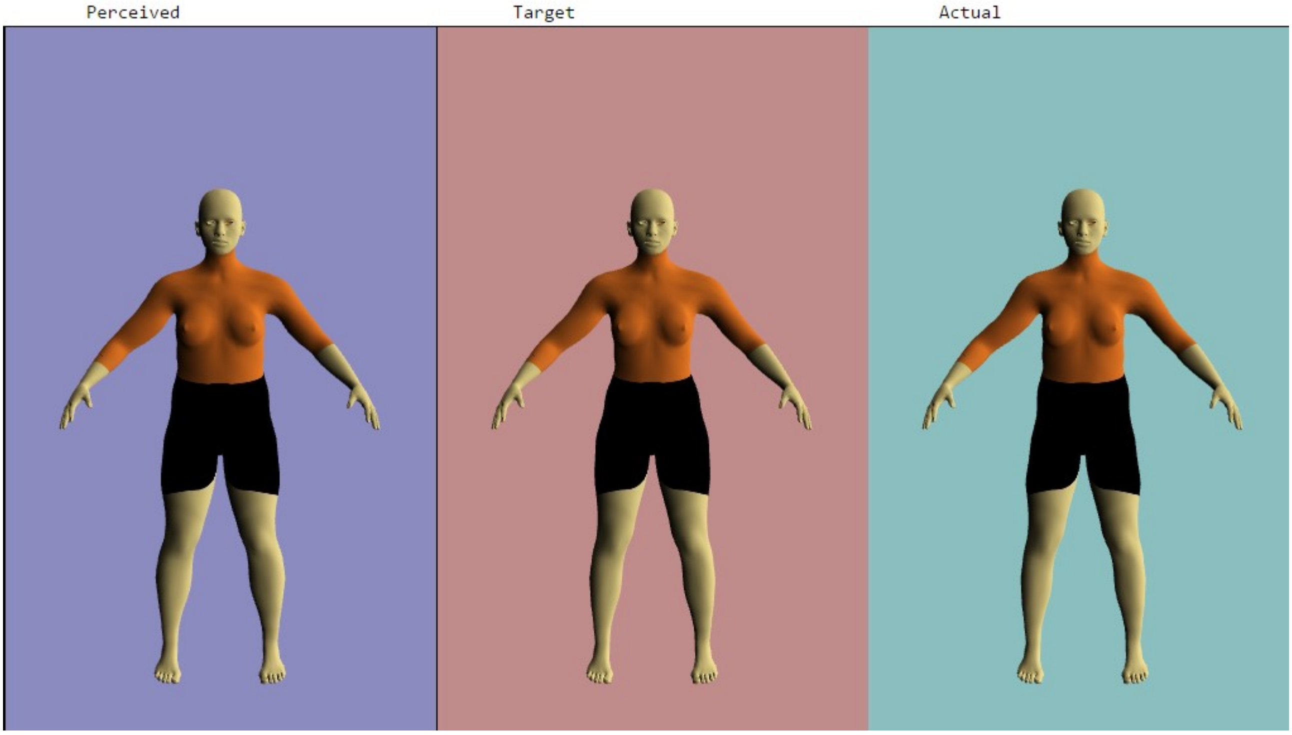
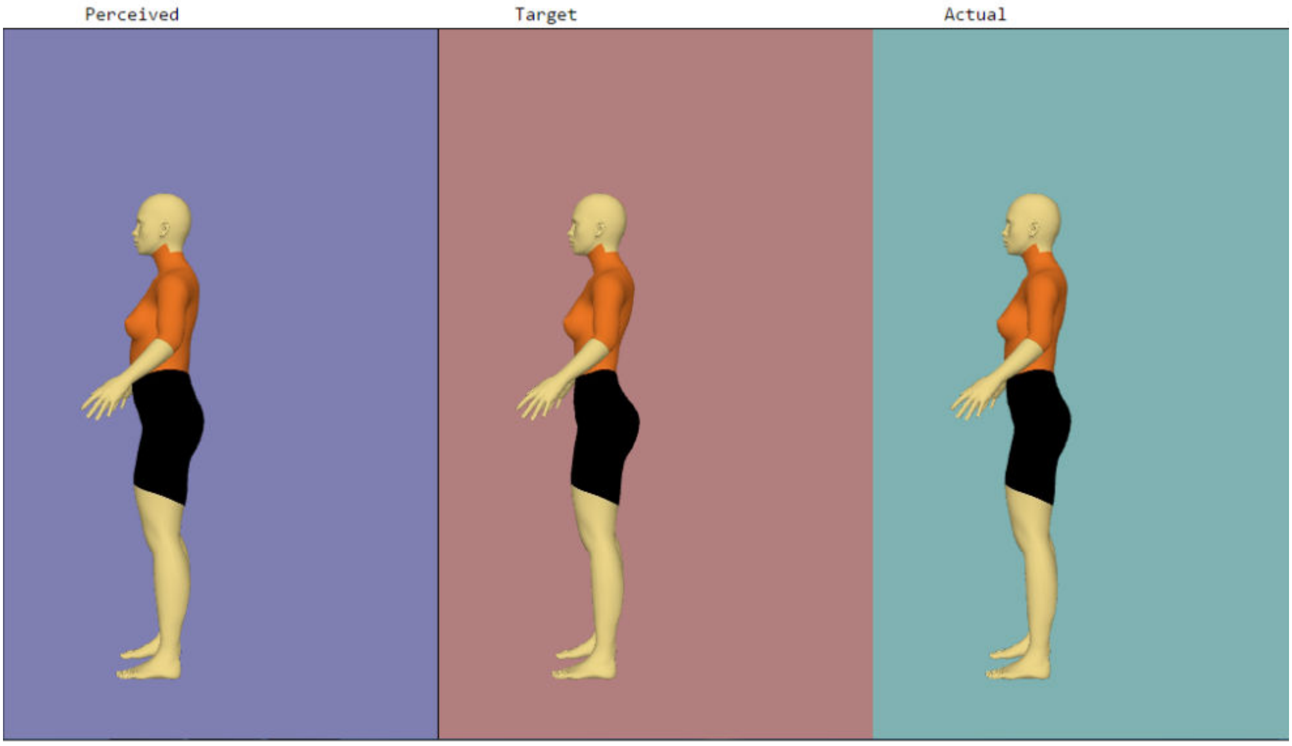


Figure 3. Example of three female avatars (side view).



Analysis

SPSS version 23 (IBM Corp) was used to conduct the descriptive statistics of the sample. The adolescents' reactions to the MYA app were analyzed using content analysis [25]. The content analysis process included three phases: preparation, organizing, and reporting. The preparation phase included selecting the unit of analysis and classifying the data as a whole. The organizing phase included developing a categorization matrix and coding the data per the categories. The reporting phase included the results of the analyzing process and the results. The frequencies of the Software Usability Survey were analyzed and calculated into percentages.

Results

The sample characteristics for prototype testing are highlighted in Table 1, with the majority of the adolescents being female (28/42, 67%), age 16 years (16/42, 38%), white (35/42, 83%), non-Hispanic (36/42, 86%), in grade 10 (20/42, 48%), healthy weight for females (23/28, 82%), and obese for males (7/14, 50%).

Table 1. Sample characteristics of the adolescents (N=42).

Sample characteristics		n (%)
Age in years		
	15	12 (29)
	16	16 (38)
	17	11 (26)
	18	3 (7)
Gender		
	Female	28 (67)
	Male	14 (33)
Race		
	White	35 (83)
	More than one race	2 (5)
	Asian	2 (5)
	Black American Indian	2 (5)
	American Indian	1 (2)
Ethnicity		
	Hispanic	6 (14)
	Non-Hispanic	36 (86)
Grade level		
	9	2 (5)
	10	20 (47)
	11	16 (38)
	12	4 (10)
Female BMI[a] -for-age category[b]		
	Underweight	0 (0)
	Healthy weight	23 (82)
	Overweight	4 (14)
	Obese	1 (4)
Male BMI-for-age category[b]		
	Underweight	0 (0)
	Healthy weight	4 (29)
	Overweight	3 (21)
	Obese	7 (50)

[a]BMI: body mass index.

[b]Underweight: less than the 5th percentile; healthy weight: 5th percentile up to the 85th percentile; overweight: 85th to less than the 95th percentile; obese: equal to or greater than the 95th percentile.

To determine acceptability, the adolescents' responses to the reaction questions (see Table 2) were analyzed using content analysis [25]. When asked what the adolescents thought about being able to view the avatars of themselves, 37 out of 42 adolescents (88%) provided positive feedback. For example, one adolescent commented about the actual and target representations: "I think it's good to see what you actually look like, then being able to see what your personal target is" (healthy-weight, 15-year-old female).

Another adolescent compared the app to the mirror: "It's nice to see what I actually look like opposed to looking in the mirror" (obese, 16-year-old male). When asked if the avatars were a good representation of themselves, 38 out 42 (90%) responded "yes." One adolescent explained the following: "Yes, because it shows what my body looks like and what I think it looks like" (healthy-weight, 16-year-old female).

Another adolescent indicated how this was something new: "Yes, I've never done something like this. I think it is a good representation" (overweight, 17-year-old male). One adolescent did not think it was a good representation: "Not really, because I think more measurements should be taken" (obese, 18-year-old male).

When asked if they were comfortable viewing the avatars, 41 out of 42 (98%) indicated they were comfortable. The research team categorized the level of comfort into three categories: very comfortable, somewhat comfortable, and comfortable based on the explanations the adolescents provided (see Table 2). Almost half of the adolescents (18/42, 43%) were very comfortable creating and viewing their avatars. When asked if the adolescents would use the avatars in the future to see how their bodies changed, 41 out of 42 (98%) responded "yes" (see Table 2).

The adolescents explained the reasons they would use the app in the future. Most of the adolescents indicated they would use the app to track progress and goals (15/42, 36%) and to see the changes or differences in their body parts (11/42, 26%). The following are examples of why the adolescents would use the avatars in the future:

> *Yes, it would be very helpful because sometimes your progress can't be seen on the body but is realized in measurements or on other body/perspectives.* [Healthy-weight, 16-year-old female]

Yes, because visual representation would help build confidence in achieving the goal. [Overweight, 16-year-old female]

> *Yes, I would like to see the pictures of my before and after results.* [Obese, 16-year-old male]

There were several reasons the adolescents liked the avatars. Almost half of the adolescents (18/42, 43%) indicated they liked how the avatars were realistic, while almost a third (15/42, 29%) liked how they could move the avatars to see them from different angles (see Table 2). Adolescents commented on what they liked:

That they are suited for the gender that you are and body type. [Healthy-weight, 17-year-old female].

I like how they're realistic. [Healthy-weight, 15-year-old female].

How you can play around with them and see what you look like with certain numbers. [Obese, 16-year-old male].

When asked what the adolescents did not like about the avatars, approximately one-third (13/42, 31%) indicated there were not enough details or customization options with the avatars, while 13 out of 42 (31%) commented there was nothing to dislike.

They do not show definition of muscle. (Obese, 16-year-old male).

They don't have as much detail, with looks and more measurements. (Healthy-weight, 16-year-old female).

The suggestions the adolescents made when asked about what they would change about the avatars included the appearance of the avatars, such as the clothing, hair, etc (16/18, 38%). One participant stated, "I think I would change the avatars to look more like the person making the avatar so they can really feel more into it and help view the different avatars of the person" (healthy-weight, 16-year-old female).

Table 2. Responses to the questions identified by the adolescents (N=42).

Questions and answers		n (%)
What do you think about being able to view avatars of yourself?		
	Positive feedback	37 (88)
	Neutral feedback	4 (10)
	Negative feedback	1 (2)
Do you think the avatars are a good representation of yourself?		
	Yes	38 (90)
	No	4 (10)
How comfortable were you creating and viewing your avatars?		
	Very comfortable	18 (43)
	Comfortable	15 (36)
	Somewhat comfortable	8 (19)
	Neutral	1 (2)
In the future, would you use these avatars to see how your body parts are changing?		
	Yes	41 (98)
	No	1 (2)
Reasons the teenagers would use the app in the future		
	To track progress/goals	15 (36)
	To see the changes/differences in body parts	11 (26)
	Helpful to see visual representations	8 (19)
	Accurate representations	4 (10)
	It was fun/interesting	2 (5)
	Yes, with no explanation	1 (2)
	No	1 (2)
What do you like about the avatars?		
	Exact/actually look like/realistic	18 (43)
	Ability to move them/3D	12 (29)
	Ability to compare avatars	4 (10)
	It was fun/cool	3 (7)
	Others' perspective	2 (5)
	App is anonymous	1 (2)
	Target Avatar	1 (2)
	No response	1 (2)
What do you not like about the avatars?		
	Needs more details/customization	13 (31)
	Nothing	13 (31)
	Appearance of avatars/clothes	8 (19)
	Difficulty seeing body changes made	3 (7)
	Not accurate	2 (5)
	Uncomfortable to see self	2 (5)
	Difficulty moving avatars	1 (2)
What would you change about the avatars?		
	Appearance of avatars/clothing	16 (38)

Questions and answers		n (%)
	Nothing	9 (22)
	Add more details	8 (19)
	Able to see body changes better	7 (17)
	Able to move avatars better	1 (2)
	Add diet to the app	1 (2)

The results of the 7-point Software Usability Survey indicated that the adolescents found the app simple to navigate (rating of 6 or 7; 40/42, 95%), found it easy to control the viewing of the avatars (rating of 6 or 7; 31/42, 74%), and found it easy to manipulate each body part and make it look muscular (rating of 6 or 7; 24/42, 57%). The adolescents had the need to look for help several times (rating of 1 or 2; 42/42, 100%), had a better understanding of what the three avatars are and how to view them (rating of 6 or 7; 40/42, 95%), were engaged by the app (rating of 6 or 7; 41/42, 98%), and experienced overall satisfaction with the ease of the app (rating of 6 or 7; 41/42, 98%).

Discussion

Principal Findings

The purpose of the prototype testing was to assess the acceptability and usability of an avatar-based, theoretically derived mobile app, the MYA app. Prior to the app being ready for prototype testing, two phases were completed that consisted of classification and development. Once completed, the app prototype was tested with a sample of male and female high school adolescents. The adolescents created and viewed the three avatars: *Perceived Avatar*, *Target Avatar*, and *Actual Avatar*. The adolescents had positive reactions to the avatar app and being able to view avatars that represented them. Almost all of the adolescents indicated some level of comfort viewing the avatars and would use the app in the future to see how their bodies change over time.

Adolescents who evaluated a Web-based substance abuse intervention also indicated high ratings for overall usability features such as ease of use and future use [26]. The ease of manipulation of the body parts and making the avatars look more muscular resulted in a lower-percentage rating from the adolescents than the other usability survey items. The responses regarding the viewing of the avatars support this lower score. The adolescents indicated that more details and customization of the avatar bodies were needed and that it was difficult to see the changes made to the avatars. These responses may explain the lower ease of manipulation score. In further adaptations, there is a need for the avatar bodies to be more detailed with an easier view of the body changes from one avatar to the next.

The adolescents indicated they would use the avatars in the MYA app in the future to monitor their body shape changes. This is similar to participants who were assigned a virtual representation of their physical selves, an unchanging virtual representation, or no virtual representation. Those who witnessed the virtual representation of their physical selves engaged in more voluntary physical activity than those who saw an unchanging virtual self or no virtual representation [8].

Ridgers and colleagues [27] conducted a systematic review of the effectiveness of youth wearable tracker devices to increase physical activity levels among children and adolescents. They found these devices have the potential to increase activity levels as the adolescents self-monitor their progress and set their goals. The MYA app is similar in that it can be used to provide feedback of their body shape progress and monitor their goals. Ridgers and colleagues [27] recommended that research be conducted to establish how youth engage with technology over longer periods of time. The adolescents indicated future use of the MYA app; however, more research is needed to examine their engagement with the app over time.

Limitations

This study is not without limitations. Due to the sample of adolescents being relatively small and nondiverse, there was not enough power to detect group differences. Another limitation is that the adolescents only tested the app at one session. To understand the acceptability and usability over time, it is necessary for the adolescents to interact with the app over a longer period of time with several recurrent uses. The app did not have this capability at the time of testing.

Implications

This app allows teens to have visual representations of their bodies—perceived, target, and actual avatars— interactive individualized programs, access to immediate feedback, and a method to monitor changes to their bodies as a result of positive changes in health behaviors. This visual representation is different from what adolescents currently have access to, such as digital scales and BMI calculators. Adolescents continue to be overweight and obese while physical activity decreases as they get older. Adolescents who identify with and use these avatars who represent them can monitor and reach their body shape and health goals. While this app may be user driven, it also has the capability for health care providers, parents, and adolescents to have a visual communication tool to discuss adolescents' body perceptions and goals.

Conclusions

Avatar-based mobile apps, such as the MYA app, provide immediate feedback and allow users to engage with images that are personalized to represent their perceptions and actual body images. Adolescents appreciate the use of weight-related messages that are personalized for them [28]. The high school students found the avatars of the MYA app easy to use, were comfortable viewing their avatars, and would use the avatars in the future to monitor how their body changes. Overall, they were satisfied with the MYA app; however, they made suggestions on how to make the app more appealing to high school males and females. This pilot study adds to the increasing but limited research of using games to improve health outcomes among high school adolescents. There is a need to further adapt the MYA app and gather feedback from a larger number of high school adolescents, including those from disadvantaged backgrounds, while testing adherence to the app over time.

Acknowledgments

We would like to thank the graduate engineering students for help in developing the app prototype for testing. We are grateful for the local high school's athletic trainer, graduate student trainers, and the high school students willing to be a part of these studies on body perceptions.

Conflicts of Interest

None declared.

References

1. Bruner MW, Chad KE, Beattie-Flath JA, Humbert ML, Verrall TC, Vu L, et al. Examination of physical activity in adolescents over the school year. Pediatr Exerc Sci 2009 Nov;21(4):421-435. [Medline: 20128362]
2. Ingledew D, Sullivan G. Effects of body mass and body image on exercise motives in adolescence. Psychol Sport Exerc 2002;3(4):323-338. [doi: 10.1016/S1469-0292(01)00029-2]
3. Oenema A, Brug J. Exploring the occurrence and nature of comparison of one's own perceived dietary fat intake to that of self-selected others. Appetite 2003 Dec;41(3):259-264. [Medline: 14637324]
4. Bittner FH, Diamond J, Myers R, Gill JM. Perception, intention, and action in adolescent obesity. J Am Board Fam Med 2008;21(6):555-561 [FREE Full text] [doi: 10.3122/jabfm.2008.06.070184] [Medline: 18988723]
5. Maximova K, McGrath JJ, Barnett T, O'Loughlin J, Paradis G, Lambert M. Do you see what I see? Weight status misperception and exposure to obesity among children and adolescents. Int J Obes (Lond) 2008 Jun;32(6):1008-1015. [doi: 10.1038/ijo.2008.15] [Medline: 18317474]
6. Liechty JM. Body image distortion and three types of weight loss behaviors among nonoverweight girls in the United States. J Adolesc Health 2010 Aug;47(2):176-182. [doi: 10.1016/j.jadohealth.2010.01.004] [Medline: 20638010]
7. Davis R, Campbell R, Hildon Z, Hobbs L, Michie S. Theories of behaviour and behaviour change across the social and behavioural sciences: A scoping review. Health Psychol Rev 2015 Sep;9(3):323-344 [FREE Full text] [doi: 10.1080/17437199.2014.941722] [Medline: 25104107]
8. Bandura A. Social cognitive theory of mass communication. In: Bryant J, Zillmann D, editors. Media Effects: Advances in Theory and Research. 2nd edition. Mahwah, NJ: Lawrence Erlbaum Associates; 2008:121-154.
9. Skinner H, Biscope S, Poland B, Goldberg E. How adolescents use technology for health information: Implications for health professionals from focus group studies. J Med Internet Res 2003 Dec 18;5(4):e32 [FREE Full text] [doi: 10.2196/jmir.5.4.e32] [Medline: 14713660]
10. Randall W, Rickard N. Development and trial of a mobile experience sampling method (m-ESM) for personal music listening. Music Percept 2013;31(2):157. [doi: 10.1525/mp.2013.31.2.157]
11. Reid SC, Kauer SD, Khor AS, Hearps SJ, Sanci LA, Kennedy AD, et al. Using a mobile phone application in youth mental health - An evaluation study. Aust Fam Physician 2012 Sep;41(9):711-714. [Medline: 22962650]
12. Harrison V, Proudfoot J, Wee PP, Parker G, Pavlovic DH, Manicavasagar V. Mobile mental health: Review of the emerging field and proof of concept study. J Ment Health 2011 Dec;20(6):509-524. [doi: 10.3109/09638237.2011.608746] [Medline: 21988230]
13. Bandura A, Huston AC. Identification as a process of incidental learning. J Abnorm Soc Psychol 1961 Sep;63(2):311-318. [doi: 10.1037/h0040351] [Medline: 13864604]
14. Fisher JD, Fisher WA, Bryan AD, Misovich SJ. Information-motivation-behavioral skills model-based HIV risk behavior change intervention for inner-city high school youth. Health Psychol 2002 Mar;21(2):177-186. [Medline: 11950108]
15. Tukatech. MyBodee URL: http://www.tukatech.com/styku [accessed 2017-02-24] [WebCite Cache ID 6oWP313RW]
16. Stahl T, Völter M, Bettin J, Haase A, Helsen S. Model-Driven Software Development: Technology, Engineering, Management. Chichester, UK: John Wiley & Sons; 2006.
17. McCurdie T, Taneva S, Casselman M, Yeung M, McDaniel C, Ho W, et al. mHealth consumer apps: The case for user-centered design. Biomed Instrum Technol 2012;Suppl:49-56. [doi: 10.2345/0899-8205-46.s2.49] [Medline: 23039777]
18. Bastioni M, Re S, Misra S. Ideas and methods for modeling 3D human figures: The principal algorithms used by MakeHuman and their implementation in a new approach to parametric modeling. In: Proceedings of the 1st Bangalore Annual Compute Conference. New York, NY: ACM; 2008 Presented at: The 1st Bangalore Annual Compute Conference; January 18-20, 2008; Bangalore, India.

19. Marrin C. Khronos. 2011 Feb 10. WebGL Specification URL: https://www.khronos.org/registry/webgl/specs/1.0.0/ [accessed 2017-02-14] [WebCite Cache ID 6oHfuZojg]
20. Blender. URL: https://www.blender.org/ [accessed 2017-02-10] [WebCite Cache ID 6oAqLWOOP]
21. Crockford D. IETF Tools. 2006 Jul. The application/json media type for JavaScript Object Notation (json) URL: https://tools.ietf.org/html/rfc4627 [accessed 2017-02-14] [WebCite Cache ID 6oHg2zld4]
22. Cabello R. GitHub. 2010. JavaScript 3D library URL: https://github.com/mrdoob/three.js/ [accessed 2017-02-14] [WebCite Cache ID 6oHgKBEWz]
23. Brown W, Yen P, Rojas M, Schnall R. Assessment of the Health IT Usability Evaluation Model (Health-ITUEM) for evaluating mobile health (mHealth) technology. J Biomed Inform 2013 Dec;46(6):1080-1087 [FREE Full text] [doi: 10.1016/j.jbi.2013.08.001] [Medline: 23973872]
24. Brooke J. SUS: A 'quick and dirty' usability scale. In: Jordan PW, Thomas B, Weerdmeester BA, McClelland IL, editors. Usability Evaluation in Industry. London, UK: Taylor & Francis; 1996:189-194.
25. Elo S, Kyngäs H. The qualitative content analysis process. J Adv Nurs 2008 Apr;62(1):107-115. [doi: 10.1111/j.1365-2648.2007.04569.x] [Medline: 18352969]
26. Raghupathy S, Forth AL. The HAWK2 program: A computer-based drug prevention intervention for Native American youth. Am J Drug Alcohol Abuse 2012 Sep;38(5):461-467. [doi: 10.3109/00952990.2012.694531] [Medline: 22823599]
27. Ridgers ND, McNarry MA, Mackintosh KA. Feasibility and effectiveness of using wearable activity trackers in youth: A systematic review. JMIR Mhealth Uhealth 2016 Nov 23;4(4):e129 [FREE Full text] [doi: 10.2196/mhealth.6540] [Medline: 27881359]
28. Woolford SJ, Clark SJ, Strecher VJ, Resnicow K. Tailored mobile phone text messages as an adjunct to obesity treatment for adolescents. J Telemed Telecare 2010;16(8):458-461 [FREE Full text] [doi: 10.1258/jtt.2010.100207] [Medline: 20959393]

Abbreviations

BMI: body mass index
MYA: Monitor Your Avatar

Edited by G Eysenbach; submitted 14.07.16; peer-reviewed by J Chaplin, R Schnall, PY Yen, W Brown, M Nitsch; comments to author 20.11.16; revised version received 06.01.17; accepted 03.02.17; published 02.03.17.

Please cite as:
Lyles AA, Amresh A, Huberty J, Todd M, Lee RE
A Mobile, Avatar-Based App for Improving Body Perceptions Among Adolescents: A Pilot Test
JMIR Serious Games 2017;5(1):e4
URL: http://games.jmir.org/2017/1/e4/
doi:10.2196/games.6354
PMID:28254737

Original Paper

Can Gaming Increase Antibiotic Awareness in Children? A Mixed-Methods Approach

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Abstract

Background: e-Bug is a pan-European educational resource for junior and senior school children, which contains activities covering prudent antibiotic use and the spread, treatment, and prevention of infection. Teaching resources for children aged 7-15 years are complemented by a student website that hosts games and interactive activities for the children to continue their learning at home.

Objective: The aim of this study was to appraise young people's opinions of 3 antibiotic games on the e-Bug student website, exploring children's views and suggestions for improvements, and analyzing change in their knowledge around the learning outcomes covered. The 3 games selected for evaluation all contained elements and learning outcomes relating to antibiotics, the correct use of antibiotics, and bacteria and viruses.

Methods: A mixed methodological approach was undertaken, wherein 153 pupils aged 9-11 years in primary schools and summer schools in the Bristol and Gloucestershire area completed a questionnaire with antibiotic and microbe questions, before and after playing 3 e-Bug games for a total of 15 minutes. The after questionnaire also contained open-ended and Likert scale questions. In addition, 6 focus groups with 48 students and think-aloud sessions with 4 students who had all played the games were performed.

Results: The questionnaire data showed a significant increase in knowledge for 2 out of 7 questions (P=.01 and P<.001), whereas all questions showed a small level of increase. The two areas of significant knowledge improvement focused around the use of antibiotics for bacterial versus viral infections and ensuring the course of antibiotics is completed. Qualitative data showed that the e-Bug game "Body Busters" was the most popular, closely followed by "Doctor Doctor," and "Microbe Mania" the least popular.

Conclusions: This study shows that 2 of the e-Bug antibiotic educational games are valuable. "Body Busters" effectively increased antibiotic knowledge in children and had the greatest flow and enjoyment. "Doctor Doctor" also resulted in increased knowledge, but was less enjoyable. "Microbe Mania" had neither flow nor knowledge gain and therefore needs much modification and review. The results from the qualitative part of this study will be very important to inform future modifications and improvements to the e-Bug games.

(JMIR Serious Games 2017;5(1):e5) doi:10.2196/games.6420

KEYWORDS

antibiotic resistance; computer games; children; education; e-Bug

Introduction

There has been a continuous rise in the number of infections caused by antibiotic resistant bacteria, which, in part, has been driven by misuse of antibiotics by prescribers and patients [1-4]. The World Health Organization (WHO) has stated that antibiotic resistance has the potential to affect anyone [5], and therefore is a serious and growing problem that has been labeled as "a ticking time bomb, not only for the United Kingdom but also for the world" [6]. The National Institute of Clinical Excellence has advised that schools should teach all ages about prevention of infections, self-care, and antibiotic use [7].

The e-Bug project is a pan-European initiative that aims to help "reduce the incidence of antibiotic resistance across Europe by educating future prescribers and users on prudent antibiotic use" [8]. The e-Bug website contains 2 sections, junior and senior, aimed at pupils aged 9-11 years and 12-15 years respectively. These include downloadable classroom lesson plans for teachers and fact files, quizzes, and revision guides for students. The e-Bug website also hosts several games, to be used at school or in the home, aimed at improving young people's understanding of respiratory and hand hygiene, and responsible antibiotic use [9,10].

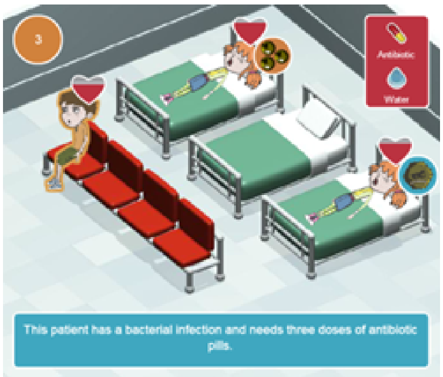
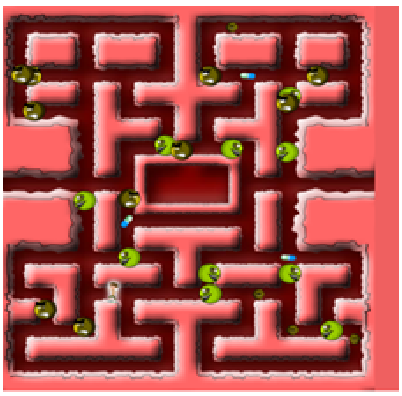
Since the 1970s, the global market for computer games has grown exponentially and games have advanced in terms of complexity, graphics, interaction, and narrative; attracting an ever-increasing number of gamers. Different theories explain how and why these games are so popular and can immerse a player for extended periods. Csikszentmihalyi theorized "flow" [11], which he described as "the state in which people are so involved in an activity that nothing else matters" [12]. The flow state has particular characteristics, including intense concentration, a sense of control of the situation, an altered personal experience of time, and a loss of reflective self-consciousness [13]. To access the flow state, an activity such as playing a computer game needs to create a balance between the difficulty of the challenge and the skills of the player [14].

In recent years, Web-based tools have been increasingly used in schools and other settings for education. Many studies have looked at the effectiveness of serious games, particularly those that cover health topics. A meta-analysis showed that serious games have a small but positive effect on healthy lifestyles and knowledge improvement [15]. Serious games are defined as games which have a primary goal of education, rather than entertainment [16].

Many educational games focus around health and science subjects. In public health, these include smoking cessation [17] and diet and exercise [18]. Web-based tools such as Twitter and social media have also been used to raise awareness and educate about antibiotics [19,20]. An antibiotic game to educate clinicians exists [21], but no material has been published on the development or evaluation of Web-based antibiotic educational games for children.

We aimed to determine the effectiveness, flow, and value of the e-Bug junior games as a resource for increasing antibiotic knowledge and awareness in primary school pupils and receive their suggestions for improvement. We selected 3 e-Bug games for this study based on their learning outcomes on antibiotic use, antibiotic resistance, and viruses or bacteria. The games are summarized in Figure 1. The aim of the e-Bug website is that children play the games in a classroom or at home, therefore, we evaluated the effect of playing all 3 games in sequence.

Figure 1. The three 3 e-Bug games evaluated in this study.

Game	Game play	Learning outcomes
Doctor Doctor 	Players treat animated patients with either antibiotics or water and bed rest, depending on whether they have a bacterial or viral infection. The game is a simple role-playing game that increases in difficulty as players treat more patients.	Antibiotics are used to treat bacterial infections. Antibiotics do not treat viral infections. Rest and fluid intake are used to treat viral infections.
Microbe Mania 	Players identify the difference between bacteria, viruses, and fungi by reading descriptions. The microbes are animated in a cartoon-caricatured style. There are 2 different levels of play.	Microbes are different sizes. Microbes can be useful and harmful. There are lots of different types of microbes.
Body Busters 	Body Busters has very similar game play to the arcade game “Pac-man”, although Pac-man, the Ghosts, and the colored circles are replaced by a little man, microbes, and antibiotic pills respectively.	You must finish the whole course of antibiotics. Antibiotics kill bacteria.

Methods

Setting

The authors invited, by email and telephone, 53 primary schools and 3 residential summer holiday schools in the Bristol and Gloucestershire area, which had not previously used the e-Bug resources in this setting, to participate. No incentives were offered.

Recruitment

Three schools that expressed initial interest were sent detailed information. This included a parental information sheet with an opt-out form attached, a teacher consent form, and examples of the questionnaire, focus group and think-aloud material to be used. Schools that expressed no interest were not recontacted. Two residential summer and 2 primary schools withdrew as the timing of the study did not fit their lesson schedule.

Sample Size

A convenience sample of 153 pupils was used from the school and summer school that responded to the invitation to participate in the study.

Ethics

Ethics approval was gained from the University of the West of England Faculty Research Ethics Committee (UWE FREC). Written consent was obtained from teachers at the participating schools, and the parents and pupils involved were given the option for pupils to opt out at any point of the data collection.

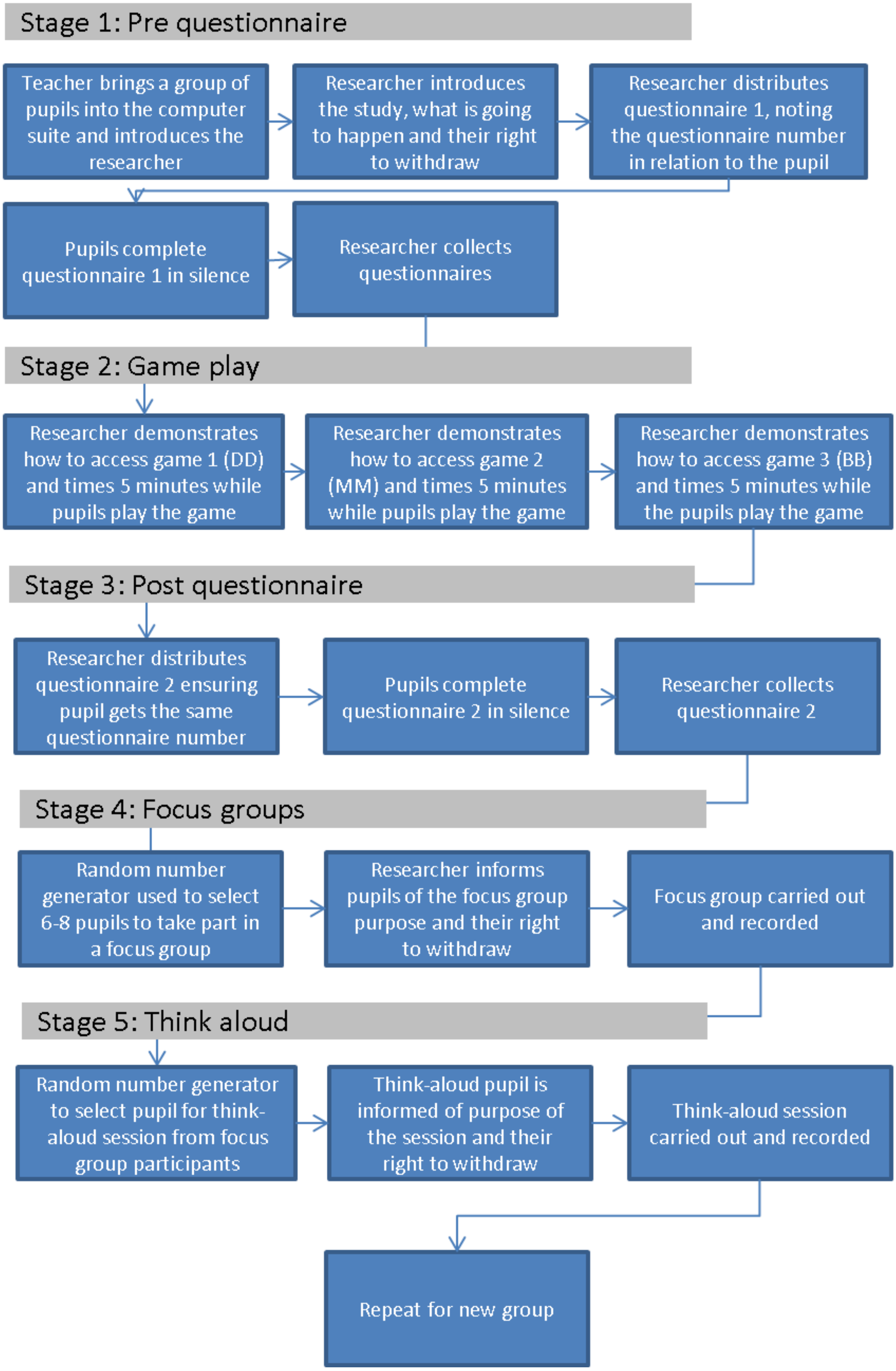
All year, 5 and 6 pupils aged 9-11 years at the primary school and all pupils aged 9-11 years at the summer holiday school had the opportunity to evaluate the games. All data collection was carried out under the supervision of teachers in computer suites in the schools. The research was carried out in groups of around 30 pupils at a time. Before and after spending 15 minutes playing the 3 games, the groups of pupils completed questionnaires in silence, to ensure no comparison of answers. They played each of the 3 games (Doctor Doctor, Microbe Mania, and Body Busters) for 5 minutes, always in that order to maintain consistency across the schools. Time was also monitored to maintain consistency. During the game play time, pupils were allowed to talk freely, which allowed the researcher to gather verbal feedback on the games.

Quantitative Data Collection

The data collection process is outlined in Figure 2. The pregame questionnaire asked 7 simple multiple-choice questions adapted from a previous e-Bug evaluation [22]. Pupils' responses were recorded as right or wrong. The answers to the questions were either available directly from information in the games or implied by in-game action (Multimedia Appendix 1) . The postgame questionnaire had identical questions. The questionnaires were matched to allow evaluation of knowledge change in individual pupils. The postgame questionnaire also asked how much the pupils liked each game, using a 10-point Likert scale and open-ended free text questions.

All incomplete answers in section 1 of the questionnaire were marked as wrong for data analysis. Questions with more than 1 answer ticked and incomplete answers in section 2 of the questionnaire were not included in the data analysis. We used a McNemar test to compare the pre- and postgame questionnaire answers, as this can compare 2 paired dichotomous variables. As statistical package for the social science (SPSS) version 20 does not provide a McNemar test without the Yates Correction (a correction for continuity used in the McNemar test that is often considered to be too conservative [23]), we employed a macro written by Marcia Garcia-Granero to remove the Yates correction [24].

Figure 2. Data collection process.



Qualitative Data Collection

After questionnaire completion, a random number generator was used to select 6 to 8 pupils to take part in a focus group at each venue. The focus group aimed to explore the usability of the games section of the website and assess the pupils' change in awareness of antibiotics. Before participation, pupils were informed of the purpose of the focus group, that it would be recorded, and that they could opt out at any point. The focus group guide asked simple open-ended questions relating to the pupils' thoughts on the games. Each focus group lasted at least ten minutes.

A think-aloud session followed the focus group. One pupil was selected randomly from the focus group at each venue and asked to describe their thoughts and feelings as they played the games. The researcher prompted the pupil to continue talking at all times and aimed to make each think-aloud session last at least five minutes. Throughout all data collection, the researcher recorded general observations and comments relating to the games in note form.

The researcher made verbatim transcripts of each session and the data were analyzed using NVivo qualitative analysis software (QSR International). Comments and interactions were marked as either positive or negative toward an aspect of the games and further divided into subgroups that related to comments about usability, style, learning experiences, or general comments.

Results

Recruitment

Ninety-three pupils aged 9-11 years were recruited from one primary school in the Bristol area and 60 pupils aged 9-11 years were recruited from a music-based summer school in Gloucestershire. In total, 153 pupils completed pre- and postgame questionnaires; 135 pupils completed the qualitative section of the post questionnaire. Forty-eight pupils completed 6 focus groups (3 groups in each venue with 8 pupils in each group) and 4 pupils (1 from the primary school and 3 from the summer school) participated in think-aloud sessions.

Likert Scale Data

Body Busters had the highest mean score of 8.2 on the Likert scale, for how much participants reported enjoying playing the game (Figure 3). Microbe Mania had a mean score of 4.7, and Doctor Doctor had a mean score of 6.8. Distribution of the scores for each game (Figure 4) shows that 73.1% (106/145) of the scores for Body Busters were 8 to 10 whereas the scores for Microbe Mania were more evenly distributed across 1-10, with only 18% (26/148) scoring 8-10. Scores for Doctor Doctor were mostly distributed between scores 4-7 and 8-10 with only 5.4% (8/147) scoring 1-3.

Figure 3. Comparison of the mean score given for each game in section 2 of the questionnaire.

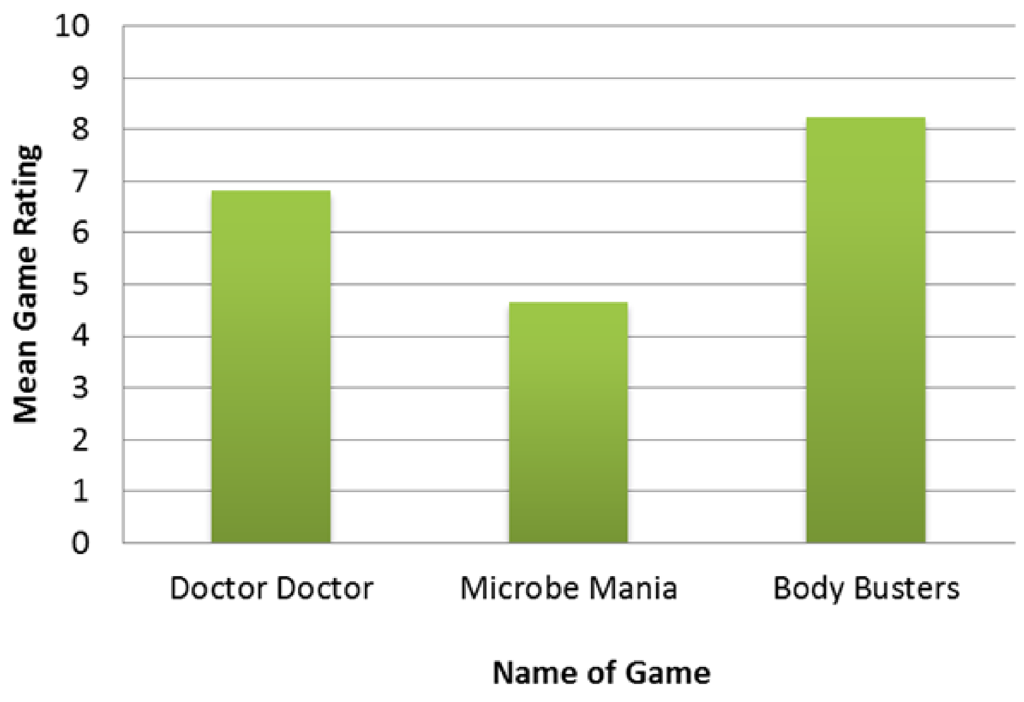
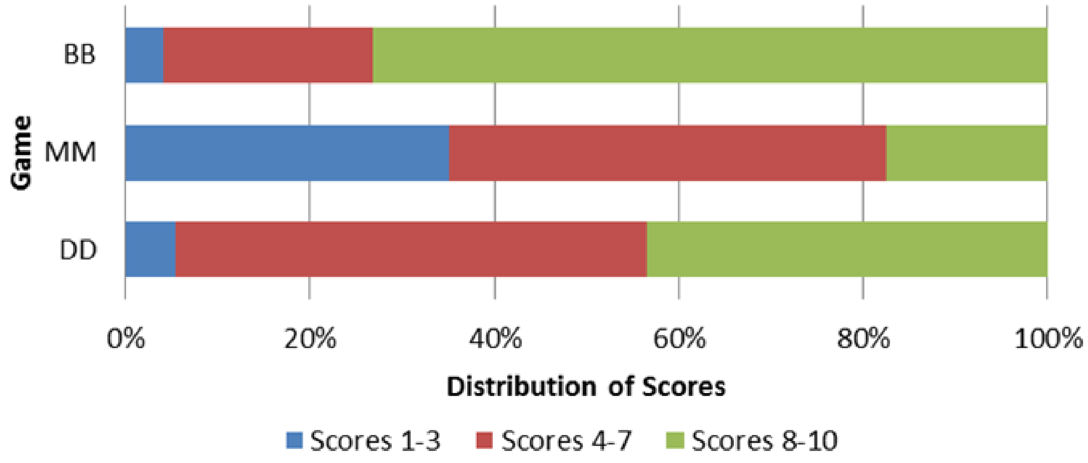


Figure 4. Comparison of the distribution of scores between the 3 games.



Qualitative Data

Doctor Doctor

Doctor Doctor received an overall positive review with many positive comments as well as suggestions for improvement.

> *I thought it was really fun in the fact that it was hard because there were 4 patients and only 3 beds* [Student, focus group 4]

Participants in the focus groups often agreed with comments made by other participants, with multiple pupils offering simple statements of agreement whenever a positive or negative statement was made. There were some negative comments surrounding the game play, including comments on how hard the game was.

> *I found it hard because I didn't really understand too well, you had to explore the controls for yourself, because the instructions aren't that good.* [Student, focus group 4]

> *I think it was actually quite frustrating too because when they were about to die you couldn't really cure them at all and it was really really bad.* [Student, focus group 5]

There were also several suggestions to extend the game to incorporate more role-playing, integrating more of a story and characterization to increase immersion.

> *Instead of them dying you could like have another level that they go into like an emergency area instead of them dying.* [Student, focus group 6]

The learning experience of Doctor Doctor was well received. Many of the pupils demonstrated awareness of the topics covered during the gameplay.

> *If you got a virus then you'd know to give the patient water and rest and if they had a bacteria then you should give them antibiotics.* [Student, focus group 6]

No participants in the think-aloud sessions or free text section of the questionnaires made any negative comments regarding the learning experience. The small number of negative comments in the focus groups mostly came from pupils who admitted that they did not read the introductory information on how to play. One pupil mentioned that they thought the colors in the game worked really well together. Although the pupils mostly liked the characters, they expressed a wish for more variation.

Microbe Mania

Microbe Mania received an overall negative review, with many negative comments and no positive comments regarding the in-game action. Common themes from the focus groups were that the game did not have many "gaming" elements and it was more like a quiz than a game.

> *It wasn't a game, it was just information.* [Student, focus group 2]

> *When we had to play microbe mania and it was the same game over and over again.* [Q 12, participant 40]

The pupils also said that the main problem was that the game needed expansion beyond the 2 short levels available, and some element of challenge. The pupils suggested the game could be improved by adding a time limit and having more and varied levels. Some of the comments regarding the lack of challenge stem from the game's mechanics that allow a player to guess the answers without repercussions, taking away the need to read any of the information, a factor that was noted by the pupils and increased some of the negative opinions of the games.

> *It also lets you do it as many times as you want to, you could literally just go for every one.* [Student, focus group 2]

> *The microbe mania needs to be longer and less boring.* [Q 13, participant 130]

The apparently poor gameplay of Microbe Mania meant the pupils lacked interest, offering many comments of "boring" in the focus groups. Microbe Mania was consistently commented on as the worst game in the free text section of the questionnaires. This correlates with observations in the researcher's field notes, that showed that the pupils very quickly became bored with this game and wanted to move on to a more interesting one. Their lack of enjoyment affected the learning experience that accompanied the game; almost no comments showed a positive learning experience in any of the data collection methods. In some brief instances pupils demonstrated the knowledge available in the game but many said that they just guessed the answers.

Body Busters

Body Busters was the most popular of the 3 games played by the pupils. When asked, the pupils consistently said that this was their favorite game. The free text questionnaire section also showed that Body Busters was very popular, with a large number of pupils writing that it was their favorite section.

> *What I like about the game is that the more you play it and you collect the more pills the less, the smaller amount of bacteria and viruses, which makes it easier.* [Think-aloud 2]

> *Yeah that was so cool, the main ones didn't go away so it was fun and challenging.* [Student, focus group 4]

> *My favourite was when we had to run away from the germs.* [Q 11, participant 112]

The few negative comments about the game mostly arose from not knowing how to play but such comments were very rare in comparison to positive comments.

> *It didn't really explain, I don't know if there was a how to play on the advert, I didn't see it.* [Student, focus group 2]

Overall, a generally positive learning experience appeared to accompany the game, although when asked what they had learnt, none of the comments were linked to the learning objectives ("you must finish the whole course of your antibiotics," and "antibiotics kill bacteria"). This was the only game that prompted further discussion directly related to any of the subjects addressed. Although the other games prompted some antibiotic or microbe-related questions, Body Busters prompted a brief discussion (below) that showed the beginning of some change in awareness about antibiotic use.

> *P: I thought pills were bad for you.*
>
> *R: You thought pills were bad for you?*
>
> *P: Because sometimes people die from having pills.*
>
> *R: Those are bad pills though, there are lots of different sorts.*
>
> *P: Aren't they drugs, the pills?*
>
> *R: Antibiotics? Pills just hold things; they can hold lots of different things so some are good for you and some are bad for you. These are antibiotics and are good at killing bad bacteria, so the ones that make you ill.*
>
> *P: There are good bacteria as well.*
>
> *R: There are good bacteria as well.* [Focus group 3, P: participant, R: researcher]

Several comments suggested improvements to the game, including improvement to the overall design.

> *Maybe for the pacmanish game it could have more characteristics for the viruses and stuff.* [Student, focus group 1]

> *And maybe more lives so you don't die as soon as you touch them. [Student, focus group 1]*

Quantitative Data

After playing, there was a small increase in the number of participants answering each question correctly (Multimedia Appendix 1). This increase ranged from 2.0% for the question, "Which of these microbes causes coughs and colds" to a 13.1% increase for the question, "Which of these would antibiotics be used for?" However, the increase was only significant for the 2 questions (5 and 7) which tested pupil's knowledge about the effectiveness of antibiotics against bacteria and viruses ($P<.05$). In question 5, 26.8% pupils (41/153) answered incorrectly before and correctly after playing the games; in question 7, 15% pupils (23/153) answered incorrectly before and correctly after playing the games.

The highest knowledge in the prequestionnaire came in the question "most coughs and colds get better without antibiotics," with 68.6% (105/153) of pupils answering correctly. The lowest knowledge in the prequestionnaire was in question 7, which focused around what antibiotics do. Only 9.2% (14/153) pupils answered this correctly, although this saw one of the largest increases in knowledge in the postquestionnaire.

Discussion

Principal Findings

This study indicates that playing the 3 games consecutively in one session had a small significant effect on pupils' knowledge of antibiotics. Body Busters, which teaches that antibiotics kill bacteria and that you must finish your whole course of antibiotics, was the most effective game for generating discussion about and increasing awareness of antibiotics. It promoted the most positive discussion about flow and enjoyment in the focus groups and ranked the highest on the Likert scales. This suggests that enjoyment of a game is an important factor in learning and in the amount of awareness a game is able to impart. Data from Doctor Doctor supports this suggestion; it received generally positive reviews but was not as successful at changing knowledge as Body Busters. None of the questions that linked to Microbe Mania had any significant change in knowledge, and qualitative data showed that it was neither popular, interesting, nor a good learning experience. This accords with Csikszentmihalyi's theory of flow, that suggests that if a player is enjoying a game then they will become more engaged with it and take in more of the available information

[11-13]. The data gathered in relation to Body Busters could demonstrate that it creates a flow-like state in players, whereas Microbe Mania does not.

Strengths and Limitations

The strengths of this study were that the data were collected in a school environment, emulating the environment where the games would normally be played as part of structured e-Bug lessons. This removes distractions that would come from carrying out the study in an environment unfamiliar to the pupils. Another strength is that the games were played together, simulating what a pupil may do during unstructured use. Finally, antibiotics are not covered in the national curriculum at this age, allowing a more accurate reflection of knowledge change due to game play.

All postgame data collection was done immediately after playing the games, therefore we do not know if the increased awareness and knowledge was either maintained or changed future behavior. The choice to collect data immediately after the pupils played the games was governed by the time constraints prevailing on the researcher and the teachers and educators at the institutions where the research was carried out.

Another limitation was that the think-aloud methodology is not well suited to being used with young pupils. The pupils aged 9-11 years who participated in this study often found it difficult to vocalize their thoughts beyond simple sentences or reading directly from the screen. The pupils' poor responses may have been due to the small sample size and chance, as the pupils were chosen at random from the group. Responses from the pupils may have been affected by the type of questions; developing simple multiple choice questions relating a complex topic such as antibiotic resistance can limit or bias the answers.

The evaluation was done after the games were played for 15 minutes in isolation, which may not mimic the natural environment for game play. The games are likely to be more effective when used to reinforce teaching in the classroom, alongside the curriculum, but more work will be needed to confirm this. A further study could ask pupils to play the games several times, to see if knowledge increases over time. The similar questions in the pre- and postgame questionnaires may cause the pupil to learn through the questionnaire rather than the game. Varying the questions asked while assessing the same learning outcomes could address this issue.

Implications

The Body Busters game was shown to be a good tool for changing awareness of antibiotics. Particular elements of the game that contribute to flow, user engagement, and enjoyment include the colorful and exciting visuals, the simple, relatable and easily understood gameplay, and the fast-paced action. Pupils suggested very few improvements other than overall expansion. An increase in knowledge on the learning outcomes could be supported by including more information in the introductory text, making the difference between viruses and bacteria more obvious, and creating a steady increase in difficulty as the game progresses.

The Doctor Doctor game is also well suited to its role in e-Bug, showing an increase in awareness for its learning objective (antibiotics are used to treat bacterial infections). Similar to Body Busters, this game uses exciting and colorful visuals and simple gameplay to encourage flow and user engagement, as well as other successful elements such as a strong narrative to "save the patients," and progressively harder and more challenging gameplay. A further increase in knowledge for the learning outcomes could be attained by lengthening the game, either with further levels using different scenarios, or a wider variety of difficulties. If further levels are included, asking the player to answer questions between levels, with in-game rewards, would benefit both knowledge on the leaning objectives and the flow.

Microbe Mania would benefit from more significant design and gameplay changes, as it offers no benefit to the website and may even detract from the overall purpose of e-Bug. Although there are a few previously identified elements of flow in this game, such as a colorful style, they do not come together to form any sort of user engagement. Increasing the overall engagement and flow could be achieved through the use of rewards for the correct answer, penalties for incorrect answers, and/or time limits for completing each level. Other improvements include increasing the text size, a much broader range of questions and answers, more levels, and a quiz at the end of the game. Although Microbe Mania has the potential to be more of an asset to the e-Bug website, feedback from teachers suggests that it should be moved to the teacher-led section of the website, as teachers find the information useful to reinforce learning outcomes in the microbes' lessons.

This study could stand as a basis for a much larger study identifying the role of educational games as teaching resources and as a broader evaluation of the e-Bug material. The e-Bug project will hopefully continue to increase awareness of antibiotics in Europe and help reduce antibiotic use, thereby reducing the rise in superbugs.

Acknowledgments

We thank all the schools, summer schools, teachers, and students who participated in the evaluation. We would also like to thank Laura Collett and Aislinn Watkins for their support and advice.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Questions and answers, where answers were available in game, and percentage of pupils that answered correctly before and after playing the games for each question (N=153).

[PDF File (Adobe PDF File), 34KB - games_v5i1e5_app1.pdf]

References

1. O'Neill J. The Review on Antimicrobial Resistance. 2016. Tackling drug-resistant infections globally: final report and recommendations URL: http://amr-review.org/ [accessed 2016-07-26] [WebCite Cache ID 6jI5znBnd]
2. Goossens H, Ferech M, Vander SR, Elseviers M, ESAC Project Group. Outpatient antibiotic use in Europe and association with resistance: a cross-national database study. Lancet 2005;365(9459):579-587. [doi: 10.1016/S0140-6736(05)17907-0] [Medline: 15708101]
3. Hawker JI, Smith S, Smith GE, Morbey R, Johnson AP, Fleming DM, et al. Trends in antibiotic prescribing in primary care for clinical syndromes subject to national recommendations to reduce antibiotic resistance, UK 1995-2011: analysis of a large database of primary care consultations. J Antimicrob Chemother 2014 Dec;69(12):3423-3430 [FREE Full text] [doi: 10.1093/jac/dku291] [Medline: 25091508]
4. Costelloe C, Metcalfe C, Lovering A, Mant D, Hay AD. Effect of antibiotic prescribing in primary care on antimicrobial resistance in individual patients: systematic review and meta-analysis. BMJ 2010;340:c2096 [FREE Full text] [Medline: 20483949]
5. World Health Organization. WHO. 2014. Antimicrobial resistance: global report on surveillance URL: http://www.who.int/drugresistance/documents/surveillancereport/en/ [WebCite Cache ID 6jI4X3Ua6]
6. Davies S. Gov.UK. 2011. Chief medical officer annual report 2011: volume 2 URL: https://www.gov.uk/government/publications/chief-medical-officer-annual-report-volume-2 [WebCite Cache ID 6jI4Kajfl]
7. National Institute for HealthCare Excellence. NICE. 2016. Antimicrobial stewardship - changing risk-related behaviours in the general population URL: https://www.nice.org.uk/guidance/indevelopment/gid-phg89/documents [accessed 2016-07-26] [WebCite Cache ID 6jHwXYIRI]
8. McNulty CA, Lecky DM, Farrell D, Kostkova P, Adriaenssens N, Koprivová HT, et al. Overview of e-Bug: an antibiotic and hygiene educational resource for schools. J Antimicrob Chemother 2011 Jun;66 Suppl 5:v3-12 [FREE Full text] [doi: 10.1093/jac/dkr119] [Medline: 21680584]
9. Farrell D, Kostkova P, Lazareck L, Weerasinghe D, Weinberg J, Lecky DM, et al. Developing e-Bug web games to teach microbiology. J Antimicrob Chemother 2011 Jun;66 Suppl 5:v33-v38 [FREE Full text] [doi: 10.1093/jac/dkr121] [Medline: 21680585]
10. Farrell D, Kostkova P, Weinberg J, Lazareck L, Weerasinghe D, Lecky DM, et al. Computer games to teach hygiene: an evaluation of the e-Bug junior game. J Antimicrob Chemother 2011 Jun;66 Suppl 5:v39-v44 [FREE Full text] [doi: 10.1093/jac/dkr122] [Medline: 21680586]
11. Csikszentmihalyi M. Beyond Boredom and Anxiety. San Francisco, CA: Jossey-Bass, Wiley; 2000.
12. Csikszentmihalyi M. Flow: The Psychology of Optimal Experience. New York: Harper Perennial Modern Classics; 1990.
13. Nakamura JC. The concept of flow. In: Handbook of Positive Psychology. New York: Oxford University Press; 2001:978-994.
14. Murphy C. Game Design Zen. 2011. Why games work and the science of learning URL: http://www.goodgamesbydesign.com/Files/WhyGamesWork_TheScienceOfLearning_CMurphy_2011.pdf [accessed 2017-03-17] [WebCite Cache ID 6p1zeayzq]
15. DeSmet A, Van Ryckeghem D, Compernolle S, Baranowski T, Thompson D, Crombez G, et al. A meta-analysis of serious digital games for healthy lifestyle promotion. Prev Med 2014 Dec;69:95-107. [doi: 10.1016/j.ypmed.2014.08.026] [Medline: 25172024]
16. Breuer J, Bente G. Why so serious? on the relation of serious games and learning. J Computer Game Culture 2010;4(1):7-24.
17. DeLaughter KL, Sadasivam RS, Kamberi A, English TM, Seward GL, Chan SW, et al. Crave-Out: a distraction/motivation mobile game to assist in smoking cessation. JMIR Serious Games 2016 May 26;4(1):e3 [FREE Full text] [doi: 10.2196/games.4566] [Medline: 27229772]
18. Shiyko M, Hallinan S, Seif EM, Subramanian S, Castaneda-Sceppa C. Effects of playing a serious computer game on body mass index and nutrition knowledge in women. JMIR Serious Games 2016 Jun 02;4(1):e8 [FREE Full text] [doi: 10.2196/games.4977] [Medline: 27255497]
19. Kendra RL, Karki S, Eickholt JL, Gandy L. Characterizing the discussion of antibiotics in the twittersphere: what is the bigger picture? J Med Internet Res 2015;17(6):e154 [FREE Full text] [doi: 10.2196/jmir.4220] [Medline: 26091775]
20. Zowawi HM, Abedalthagafi M, Mar FA, Almalki T, Kutbi AH, Harris-Brown T, et al. The potential role of social media platforms in community awareness of antibiotic use in the Gulf Cooperation Council States: luxury or necessity? J Med Internet Res 2015 Oct 15;17(10):e233 [FREE Full text] [doi: 10.2196/jmir.3891] [Medline: 26471079]
21. Castro-Sánchez E, Charani E, Moore L, Gharbi M, Holmes A. “On call: antibiotics”- development and evaluation of a serious antimicrobial prescribing game for hospital care. In: Games for Health 2014. Wiesbaden: Springer; 2014:1-7.

22. Lecky DM, McNulty CA, Touboul P, Herotova TK, Benes J, Dellamonica P, et al. Evaluation of e-Bug, an educational pack, teaching about prudent antibiotic use and hygiene, in the Czech Republic, France and England. J Antimicrob Chemother 2010 Dec;65(12):2674-2684 [FREE Full text] [doi: 10.1093/jac/dkq356] [Medline: 20956353]
23. Thompson B. Misuse of chi-square contingency-table test statistics. Educ Psychol Res 1988;8(1):39-49.
24. How2stats. 2011. Two proportions test (related) - SPSS URL: http://www.how2stats.net/2011/09/two-proportions-test-related-spss.html [accessed 2016-07-26] [WebCite Cache ID 6jHwArxJJ]

Edited by G Eysenbach; submitted 28.07.16; peer-reviewed by E de Quincey, A Ridgway, D Dockterman; comments to author 20.11.16; revised version received 20.12.16; accepted 18.02.17; published 24.03.17.

Please cite as:
Hale AR, Young VL, Grand A, McNulty CAM
Can Gaming Increase Antibiotic Awareness in Children? A Mixed-Methods Approach
JMIR Serious Games 2017;5(1):e5
URL: http://games.jmir.org/2017/1/e5/
doi:10.2196/games.6420
PMID:28341618

Original Paper

User-Centered Design of Serious Games for Older Adults Following 3 Years of Experience With Exergames for Seniors: A Study Design

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Abstract

Background: Seniors need sufficient balance and strength to manage in daily life, and sufficient physical activity is required to achieve and maintain these abilities. This can be a challenge, but fun and motivational exergames can be of help. However, most commercial games are not suited for this age group for several reasons. Many usability studies and user-centered design (UCD) protocols have been developed and applied, but to the best of our knowledge none of them are focusing on seniors' use of games for physical activity. In GameUp, a European cofunded project, some prototype Kinect exergames to enhance the mobility of seniors were developed in a user-centered approach.

Objective: In this paper we aim to record lessons learned in 3 years of experience with exergames for seniors, considering both the needs of older adults regarding user-centered development of exergames and participation in UCD. We also provide a UCD protocol for exergames tailored to senior needs.

Methods: An initial UCD protocol was formed based on literature of previous research outcomes. Senior users participated in UCD following the initial protocol. The users formed a steady group that met every second week for 3 years to play exergames and participate in the UCD during the 4 phases of the protocol. Several methods were applied in the 4 different phases of the UCD protocol; the most important methods were structured and semistructured interviews, observations, and group discussions.

Results: A total of 16 seniors with an average age above 80 years participated for 3 years in UCD in order to develop the GameUp exergames. As a result of the lessons learned by applying the different methodologies of the UCD protocol, we propose an adjusted UCD protocol providing explanations on how it should be applied for seniors as users. Questionnaires should be turned into semistructured and structured interviews while user consultation sessions should be repeated with the same theme to ensure that the UCD methods produce a valid outcome. By first following the initial and gradually the adjusted UCD protocol, the project resulted in exergame functionalities and interface features for seniors.

Conclusions: The main lessons learned during 3 years of experience with exergames for seniors applying UCD are that devoting time to seniors is a key element of success so that trust can be gained, communication can be established, and users' opinions can be recorded. All different game elements should be taken into consideration during the design of exergames for seniors even if they seem obvious. Despite the limitations of this study, one might argue that it provides a best practice guide to the development of serious games for physical activity targeting seniors.

(JMIR Serious Games 2017;5(1):e2) doi:10.2196/games.6254

KEYWORDS

user studies; usability testing; gestural input; user-centred design; accessibility; consumer health; exergames; participatory design; lessons learned

Introduction

Overview

Physical activity is important at all ages, and seniors particularly need sufficient strength, balance, and flexibility to manage in everyday life. This is particularly true for those ages 65 years and older.

Exergames can be a method to motivate seniors to exercise and hence get more physical activity with sufficient physical exertion [1]. Most commercial games are, however, not suited for this group for several reasons including speed, amount of information, required movements, etc [2-4].

GameUp, a project cofunded by the European Union, Spain, Norway, and Switzerland [5,6] aimed at creating useful and motivational exergames for seniors, was undertaken with a user-centered approach during the design and development process to meet the users' limitations and requirements.

Despite the fact that many usability studies and user-centered design (UCD) protocols have been developed, to the best of our knowledge none of them have focused on seniors' use of games for physical activity (ie, exergames). Furthermore, there is limited information regarding the design and functionality of serious games for seniors and more specifically for exergames. An initial UCD protocol was created based on literature and previous research outcomes in order to develop the GameUp project exergames. During the project, we followed that protocol and adjusted it based on 3 years' experience in order to meet the needs of both the project and the users. In this paper we report the lessons learned for the different phases of the protocol and the adjustments that our initial protocol needed in order to be applicable to older adults and we highlight the most important UCD influences and recommendations on the GameUp exergames.

The remainder of the paper is structured as follows. Initially, we set the scene by pinpointing the need for unique design for seniors, exploring the UCD, and identifying the need for a specific UCD for seniors. In the Methods section we describe all the necessary elements of lessons learned, namely the UCD protocol which served as the base of our exergames implementation, the recruitment criteria for the seniors, the GameUp exergames, and the considered ethical aspects and risks. Next, the Results section describes the lessons learned from a 3-point view: (1) the lessons learned during the different protocol phases, (2) changes and tips for our initial protocol on the different methodologies of the UCD protocol, and (3) the lessons learned from the important changes of our developed exergames. The Results section points out the initial protocol's weaknesses against the existing literature including the limitations of our approach. Finally, the Conclusions section sums up the lessons learned and emphasizes the key issues on applying UCD with seniors.

Why a Unique Design for Seniors?

It has been established in several studies that seniors enjoy playing exergames and they believe exergames can assist in maintaining physical activity [7-12]. Despite the fact that balance and rehabilitation of seniors can be maintained and improved through exergames [2,3,7,8,13-16], not many are designed for this age group [11,17,18]. Game designers use their creativity for game ideas, but since designers normally are young, they do not often consider the needs of seniors [19]. The game stories might therefore not be of interest for the senior population.

A trial using Nintendo Wii exergames for seniors indicated that age-related impairments influence the use of video games among frail elderly, so this should also be considered in the design process [20]. We have indeed observed that there are many obstacles for seniors playing commercial exergames, and this has been confirmed in other studies [4,7]. Also, existing games for the young are not developed to meet the physical exercise needs of elderly people. Based on these findings we can conclude that good and safe exergames should be developed particularly for seniors, both regarding movements and narrative.

What Is User-Centered Design?

The International Organization for Standardization uses the term "human-centered design" and defines it to be an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" [21]. The same standard also states that this term in practice is used synonymously with UCD. According to Karat and Karat [22], "UCD defines iterative processes whose goal is the development of usable systems." According to Sebe [23], "user-centered design (UCD) is a process (not restricted to interfaces or technologies) in which the needs, wants, and limitations of end users of a product, service, or process are given extensive attention at each stage of the design process. UCD can be characterized as a multistage problem-solving process that not only requires designers to analyze and foresee how users are likely to use a product but also to test the validity of their assumptions with regard to user behavior in real world tests with actual users."

Since UCD can be considered a multistage process, one will normally use different methods in different stages. Both qualitative and quantitative methods were used by Proffitt and Lange [24] while implementing a UCD. They used focus groups as well as an iterative user-testing process while testing changes to a prototype. One study [25] used a 3-stage qualitative UCD approach in the requirement phase including literature search and focus groups. The actual use of UCD in the industry was studied by Vredenburg et al [26] wherein 13 methods were identified, among them field studies, user requirements analyses, iterative design, usability evaluation, task analyses, focus groups, user interviews, participatory design, and prototypes. Several of these methods have been used in our initial protocol.

Need for a Specific User-Centered Design for Seniors

Gregor et al [27] further conclude that UCD principles need to be employed for seniors. Seniors are different from the young; "functionality, needs, and wants differ from the young even though they consider themselves as fit, but many often have several physical problems with a general reduction in functionalities" [27]. The authors further refer to the difficulty both of recruiting representatives from this group and of communicating with them.

When users have special needs like the senior users do, the costs of applying UCD increases as the users have more diverse requirements [28]. Zaijcek [29] concluded that it is difficult to arrange traditional focus groups for seniors, which is a common method in UCD. Focus groups should be adapted for older people, and their organization requires considerable interpersonal skills. They conclude that interface design for seniors is more complex than for other groups.

According to Zajicek, "adults as they get older experience a wide range of age-related impairments including loss of vision, hearing, memory and mobility, the combined effects of which contribute to loss of confidence and difficulties in orientation and absorption of information" [29]. With age, eyesight and hearing deteriorate and seniors require more time to think and get an overview [10,30]. Also motoric skills deteriorate with age, and many seniors have health conditions limiting their abilities.

Dickinson et al [31] made a list of guidelines for maximizing the research outcomes of working with older adults. The test case was to learn to use email, but some of the recommendations are also valid for exergame development. One is to put great care into making sure information and instructions are understood; another is that one has to be flexible when it comes to timing during trials. They also point out the difficulties of recruitment and the importance of being able to reschedule and be flexible on timing to maintain participation in a long-term study.

Existing research on Web design for elderly people shows the importance of designing and implementing games and applications uniquely targeting elderly people. We have identified some initiatives and research aimed at providing guidelines for the design and accessibility of websites for elderly people [32-40]. AgeLight [33] points out the importance of player-centered design, meaning that the seniors should be brought in early in the design process. An affordance-based approach to designing a game was followed by Awad et al [41] emphasizing "the type of action the user can perform but also when (response times) and how it can be performed (range of motion)." In this study the authors followed an iterative testing process starting with an early prototype.

Despite the fact that some studies followed a UCD, to the best of our knowledge none of the studies coded and formed a UCD protocol for exergames targeting seniors. In addition, there are few studies that recorded the needs of the older adults either for the creation of exergames or as being part of a UCD.

Methods

Recruitment

One of the partners in the project was a senior center, and the participants in the UCD were recruited from its members. In order to ensure that participants would be available throughout the duration of the GameUp project, a regular group was formed that met every second week to play exergames and share a meal. Researchers would participate often but not at all gatherings.

All testing, interviews, etc, were performed at these gatherings. To ensure that the participants were in the target group for the GameUp project and also competent to sign an informed consent, inclusion and exclusion criteria were defined (Textbox 1).

Textbox 1. Eligibility criteria.

Inclusion criteria:

- Aged 65 years or older
- Risk of falling or history of falling
- Recent illness or surgery
- Impaired strength or balance

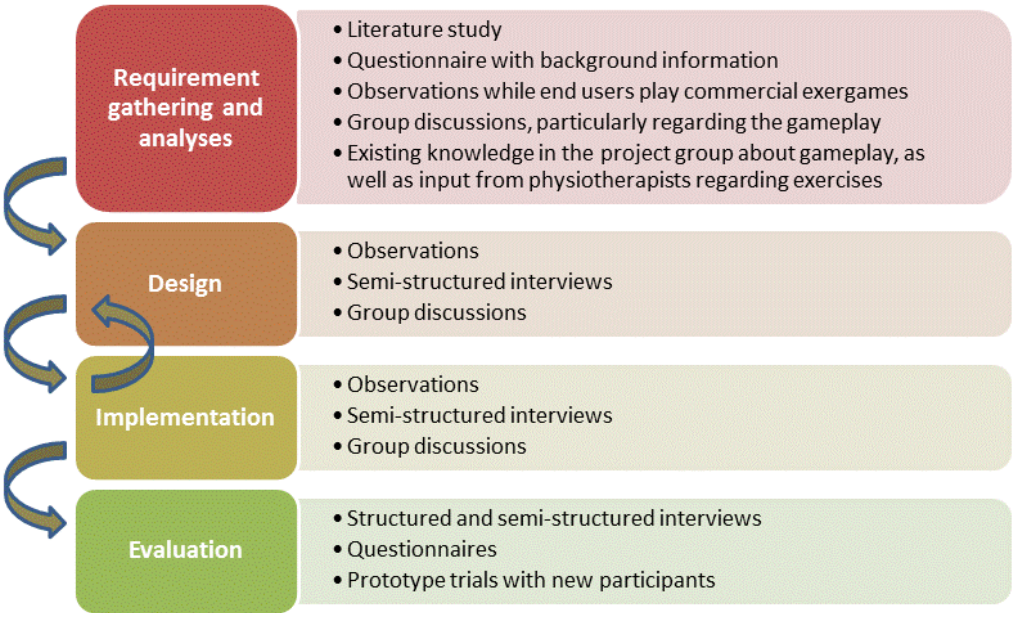
Exclusion criteria:

- Cognitive impairment, defined as a Mini Mental State Examination score below 25
- Other disease, illness, or limiting condition that would make inclusion and beneficial use of the system difficult, such as complete blindness, deafness, or severe disabilities

Definition of a High-Level Protocol for User-Centered Design of Exergames for Seniors

A high-level protocol for UCD of exergames for seniors was developed by the authors as depicted in Figure 1. This was based on the aforementioned literature and on indications through previous research engaging seniors and exergames on a much smaller scale [10]. This protocol was then tested during the GameUp project on a group of seniors over a 3-year period. A description of the design protocol and how it was used follows.

Figure 1. The 4 phases and the methods used in each of the phases.



Phases of Development

Requirement Gathering and Analyses

The main objective of this phase was to gather requirements for an initial design by collecting basic requirements and needs of the end users for the chosen group as well as requirements for the games to be developed by defining useful exercises. The methods for the user involvement in this phase included

- Literature study
- Questionnaire with background information
- Observations while end users play commercial exergames
- Group discussions
- Existing knowledge in the project group

Design

In this phase, the initial design of the games become more detailed using an iterative approach. The users should have a real opportunity to influence the outcome of the design by giving feedback. This phase includes the following methods for user involvement:

- Observations
- Semistructured interviews
- Group discussions

Implementation

The implementation phase follows an iterative approach based on feedback and user reactions. Detailed descriptions of the design may need to be adjusted merging different parts of the game. During the implementation phase, methods for user involvement are

- Observations
- Semistructured and structured interviews
- Group discussions

Evaluation

In the evaluation phase, the emphasis is on the final prototypes. The most common approach is to run pilot tests, but testing the exergame with smaller new user groups can also give valuable input. The methods for user involvement in this phase are

- Structured and semistructured interviews
- Observations
- Questionnaires
- Prototype tests with new participants

The Games

Microsoft Kinect was chosen for development based on usability studies [42]. The movements included exercises for balance, flexibility, and strength, all important for mastering daily activities.

A total of 7 minigames were developed. The 3 balance games are based on the same concept but with different graphics, and thus they appear as different games. In these games, one is supposed to catch things that fall from above. The falling items (apples, stars, and chickens) are of 2 different colors, and they need to be put in the correct basket. In addition, 4 different minigames for leg strength and flexibility were developed. Since there was a big difference in abilities in the user group, the games have several difficulty levels.

Ethical Aspects and Risks

Ethical aspects and risks must be identified, including an exit strategy if the participants are enjoying and even getting dependent on the GameUp project results. In our case there were no direct medical interventions, but many exercises are performed standing, and there could be a risk of falling. Some can play alone; for others there must either be a person or chair for support. Some will even play seated or use a walking frame.

A Berg Balance Scale was performed for all the users before the start of the UCD to define the appropriate level of exercises. To avoid any further risk, all the participants were informed about proper use of the system.

The participants have no economic interest or obligations related to the GameUp project, and participants hold the right to exit the project at any time without having to provide a reason for this and without consequences.

Ethical approval for this study was granted by the Data Protection Official for Research in Norway.

Results

Study Participants

Approximately 7 to 10 seniors would be present at each gathering, and they were retirees in the age range of 66 to 95 years. In total 16 persons participated.

All participants signed an informed consent and were aware of the fact that they were participating in a research project in which a UCD method would be followed to implement the GameUp exergames. During the 3 years, several members left the group for various reasons, and new ones were recruited. Reasons for discontinuation were varied: 1 moved to a care home far away, a couple got too sick to continue, 1 died, and 1 had a steep cognitive decline and could no longer participate.

The average age was over 80 years but because of the time span and replacements, this was not constant. The first established group consisted of 9 participants, 1 man and 8 women aged 71 to 95 years with an average age of 83 years. Toward the end of the GameUp project at the completion of the UCD protocol, there were 10 participants, 2 men and 8 women in the age range of 66 to 90 years with an average age of 81.7 years.

Lessons Learned Using User-Centered Design With Seniors

Lessons Learned During the User-Centered Design Protocol Phases

Requirement Gathering and Analyses

During this phase, a multidisciplinary team should be involved from the beginning. Important inputs for our exergames design were that physiotherapists defined suitable exercises to help the mobility of seniors, developers studied the possibilities of the different tracking movement technologies such as Wii and Kinect, and game designers considered game elements, etc.

Design

Videotaping proved to be useful in order to analyze the reactions of the users to different tests. Furthermore, we identified that all the different elements should be taken into consideration during the design of exergames for elderly, including theme, movements, user interface and interaction both with the games and the technology, colors, sounds, playability, etc. As explained above, we developed Kinect-based exercises. During the design phase, we aimed both to learn how the users reacted to this type of interface and which of the physiotherapist-defined movements would be suited for Kinect games. All the different elements were presented progressively to the users. Initially, the first design was presented to the users by presenting graphics on paper and then the interaction with the system was introduced by presenting the physical movements required. Later, design elements like sound and graphics were introduced.

Implementation

Detailed descriptions of the design were adjusted during this phase since merging different elements of the design required additional user input. Different tests of the exergames were performed using different methods depending on what was appropriate: (1) test of early prototypes, (2) iterative tests with changes according to outcomes from previous tests, (3) tests of user interface elements (coming together), and (4) test of the playability of the game with focus on game story and game theme.

Evaluation

As part of this phase we tested the final prototype with our group. We observed that the group that participated throughout the other 3 phases of the UCD protocol provided feedback during this phase as well, with a few alterations as described in the Study Participants subsection.

Lessons Learned Applying the User-Centered Design Protocol Methodologies

Our initial UCD protocol was used throughout the project in a UCD methodology although it was slightly adjusted to enable us to reach our goal. The lessons learned could be summed up as a series of tips and adjustments for the creation of serious games for seniors and are summarized in Figure 2.

Figure 2. Adjustment to initial protocol for user-centered design (UCD) design having seniors as users.

	UCD Methods	Adjustments and tips
Requirement gathering and analyses	Literature study	As it is
	Questionnaire	Should be turned into the form of Structured Interviews
	Observations while end users play commercial exergames	Use; ask users for repetitions within different sessions
	Group discussions	Use; Repeat questions to users and repeat the answers so as to make sure that the users heard them
	Existing knowledge in the project group	Take into consideration expertise in relevant fields (Physiologists, Psychologist, Physiotherapist, etc.)
Design	Observations	Use; repetitions within different sessions; Use to defined questions for group discussions and structured interviews; Pose direct questions when needed for obvious design elements
	Semi-structured interviews	At the first sessions use structured interviews and over time use semi-structures interviews
	Group discussions	Use; Repeat questions to users and repeat the answers so as to make sure that the users heard them; Repeat the testing sessions multiple times
Imple-mentation	Observations	As above
	Structured & semi-structured Interviews	As above
	Group discussions	As above
Evaluation	Structured & semi-structured Interviews	As above
	Observations	As above
	Questionnaires	Keep questions &answer choices to minimum, short and clear; Split long questionnaires to multiple sessions; Be prepared to fill out the questionnaire yourself for the user in the form of structured or semi-structured interviews; Explain if needed the question several times and politely insist of getting an answer; Simplify 5 point Likert scale to 3 points
	Prototype test with new participants	Include new groups or new users

Questionnaires in Interviews

Questionnaires were part of our initial UCD protocol during the "Requirement Gathering and Analyses" and "Evaluation" phases. In order to apply those to our user group, we realized that we had to adjust them by reducing the questions for each session because the users found it hard to concentrate for a long period and they got exhausted very quickly. If there were many questions, we would observe very visible signs of fatigue and loss of concentration.

To this extent, we completed all questionnaires in the form of structured or semistructured interviews since many of the participants had problems both reading and writing and many also had problems understanding some of the questions despite the fact that they met the inclusion and exclusion criteria. Some of the participants also tended to unintentionally skip questions, so the questionnaires have to be short and very clear if used.

When a 5-point Likert scale was used, the facilitators of the session turned the questionnaires into structured interviews as explained above. Furthermore, additional time had to be spent on getting a proper reply. For example, a common answer in this case was "That is fine" in order to avoid a thorough reply. Also the way many responded on color tests gave the impression that they wanted to tell there was nothing wrong with their eyesight instead of telling what they could see the best. Finally a different approach was taken on the questioning than first planned, resulting in minimizing both the number of questions and the number of answering options and spending more time on getting useful answers.

Semistructured and Structured Interviews

In the semistructured interviews, we had some open questions and discussions in addition to the structured interviews where we wanted to learn about users' opinions on specific topics. At the beginning of the application of the UCD protocol, we more or less only got replies to direct questions, which made us think that only structured interviews should be used, but toward the end of the application of the UCD protocol many would give their own suggestions and that allowed us to constructively include semistructured interviews.

Observations

Researchers often observed the seniors as they played both commercial games and the GameUp project–developed games. In the observations, we could see how they mastered both the game technology and the movements but also how much they did not perceive. This was particularly the case in many of the commercial games. Based on observations, we also defined questions for group discussions and structured interviews about the project games. For instance, we had the feeling that most could only see exactly what they were doing in the game even if the graphics were very simple and clear. We therefore asked whether they could see information on the top of the screen about the points earned while they were playing. In fact, nobody could see it even though they had been playing the same game several times as well as watching others play. We also observed repeated errors and could adjust the game accordingly.

We used observations to see the users' reactions to the design elements as well as to detect errors and misunderstandings. Observations also made us change graphics or parameters: the speed of the games or the placement of menu buttons, for example. We also made sure that it was possible to get information before or after gameplay instead of during the game.

Group Discussions

The setting of the group discussion was as follows: the entire group would sit in a semicircle in front of the screen with the person playing in front, and they would take turns playing (Figure 3). In between playing or before and after we would initiate small group discussions while all were seated by triggering a discussion through questions about the game, particularly if we had introduced something new. We found the setting appropriate since the users didn't have to change places between observing or playing the game and discussing. Issues we brought up during the group discussions included hearing issues of the users. Hearing is a problem for many elderly people; we experienced that we often had to repeat questions and frequently we had to repeat the responses so that all could hear what had been said.

Another important lesson learned is that replies would often come gradually playing the same game version in several sessions. Repetitions were also important to get the response from as many as possible, since there were always some who were not present at specific gatherings.

As an example of the outcome of group discussion, one theme that was successfully discussed was the perceived contents or game story. In one minigame the players perform knee bends, which results in water coming from a pump and into a bucket (Figure 4). Occasionally a cow would pass by and bellow, so many players wanted the water to run into a trough for the cows instead of a bucket. Another example is a flexibility game where the players use a scythe. Most of the players had used scythes in their youth and were a bit frustrated that it was cutting in the wrong direction. In the game, the corn was cut when the scythe was on the way back, but in reality you have to cut on the first move and then swing the scythe back.

Many changes occurred to the developed exergames through the 3 years of the GameUp project. We briefly describe the ones that can be generalized to other games in Figure 5.

Figure 3. Seated in front of the screen ready to play.

Figure 4. Bending knees to get water.

Figure 5. Most important exergames elements and functionality as resulted from 3 years of experience with exergames for seniors.

Speed

The players need to get time to understand what is going on and to plan a reaction.

• *In the apple picking game, the game stops while the players are putting an apple in the basket so they can take the time they need.*

Movements

The body becomes less flexible, and the balance is reduced. Different health issues such as knee or hip prostheses might make some movements unadvisable

• *In the first version of the apple picking game, the players would attempt to bend far down to place the apples in a basket, which could lead to a loss of balance. The baskets were placed on chairs in a later version*

Information

Seniors only have one focus of attention. Important information must come after the gameplay

• *None of the senior players could see information about the gameplay, such as scores and time left, while playing despite the size of the information unless the game stopped.*

Colours and contrasts

The eyesight deteriorates with age. More light is needed and reduced variety of colours. Graphics should be bright with good contrasts

• *In the apple picking game after several iterations the colours and contrasts have been changed*

Small details

Are lost on people who do not see so well

• *The straw and apple in (Figure 5) was perceived as a pipe, so the straw was removed.*

Text / Fonts

Fonts should be big, thick and clear. Place of the text on the screen plays important role. The less text the better. Oral feedback (recorded text) should be provided

• *Within GameUp exergames text feedback was enlarged accompanied by audio.*

Menu

Menu buttons should be large and they should have a big distance between them.

• *We placed the menu buttons in any easy to activate place, but not so that it was accidently activated, which is easily done when using Kinect.*

Sound

The volume should be the same for all the sounds

• *Sound was in some cases disturbing. Many sounds have been adjusted based on user feedback. Some feedback sounds were considered unnecessary and removed, some were added to give feedback on successful actions, some have been changed to be more pleasant.*

Lessons Learned From Exergames Targeting Seniors—Important Changes

Among the most important elements of the games were speed, both of some movements and of the game progress. In our exergames, we needed to reduce the speed of both and in addition adapt the game to the physical ability of the seniors, so we changed movements that were difficult for many elderly people to perform.

Eyesight deteriorates with age. We need more light the older we get, and we also see fewer colors. This means that graphics need to be clear and bright, and users' feedback helped us change graphics. Also small details were lost. For instance, the straw and apple in Figure 6 was perceived as a pipe, so the straw was removed. This also means that fonts must be big and clear, and there should be as little text as possible, preferably accompanied by oral feedback. Oral information is important, but sound can also be very disturbing, and many sounds have been adjusted based on user feedback.

Several menu buttons were enlarged and the distance between them increased. A menu color test was performed to find good color combinations between button, background, and text.

Figure 6. The first and a later version of an "Old farmer" character. With the straw, the players thought he was smoking a pipe.

Discussion

Prinicipal Findings

Lately research has been focusing on older adults over 65 years, including how to keep them active. Exergames seems to be a promising tool to enable elderly people to be active, but the creation of the games can be difficult since no specific guidelines exist. As participatory design is central to the creation of serious games, in this paper we propose an adjusted UCD protocol tailored to senior users and provide and discuss the lessons learned of applying this protocol over almost a 3-year period.

Taking into consideration the limitation and the cross-validation of findings through published literature, the novelty of this paper lies in the proposal of a UCD protocol and the use of its methodologies tailored to seniors' needs, lessons learned during the creation of an exergame applying a UCD approach which then can be generalized and applied in serious games targeting seniors, and lessons learned from the application of such a protocol having seniors as users. This may act as a guide for future studies and projects.

Most (exer)game developers are young, and it is difficult for the young to realize the limitations of age. This applies to graphics as well as speed and movements. It is therefore highly advisable to apply a user-centered approach when designing for seniors. It is difficult to recruit the very old, but the authors believe that the users should be as close as possible to the intended user group both in age and abilities. Senior users are often defined as being 55 years and older, but there is often a huge difference between a 55-year-old person and a 95-year-old person both in cognitive and physical abilities. In the 3-year period using user-centered design, the average age of our users was over 80 years.

One big challenge was to ensure that the participants understood the questions we posed and gave an accurate reply. For instance, the nuances were lost on a 5-point Likert scale; we propose using only 3 points when this will still give valid results (eg, "I agree," "I do not agree," and "I do not know").

Observations are very important and should be emphasized throughout the protocol, including hints for the observers about what to look for. This should include errors made during the test but also signs that the participant does not understand or cannot see details, whether there are games or parts of games they do not want to perform, etc. Filming the different tests and sessions can be of great help for later analyses.

Since group discussions can be a challenge and participation was irregular, we developed small questionnaires when we wanted to make sure that we got the opinion of as many as possible and repeated the sessions in several gatherings to get responses from most participants, sometimes even asking selected persons to arrive before the gatherings started. Further, in the group discussions we took the time to direct questions at each and every one, coming up closer to the persons to make sure that they could hear what was being said.

The very old get exhausted easily, so there should not be too many questions and certainly not too many that are almost the same. We particularly experienced this when going through color tests. We had 4 sheets, each with 5 menu buttons, and we wanted to know which ones they could see the best. Toward the end most were exhausted and did not want to continue. Tests like this should only have small samples and could be performed in more than one session.

Working with seniors requires trust, which takes time to build. The group size should not be too big for several reasons: it is difficult to recruit in this age group, the participants need to gain trust inside the group, and group discussions among the old are challenging.

Since many in this user group are more or less computer illiterate, it is also important that they understand that crashes and errors are not their fault but the developers'.

According to Faulkner [43], the number of users in a usability study probably influences the problem discovery level a study will achieve. He demonstrated that 10 users are able to identify a minimum of 82% of the problems with an average problem finding of 94.686% while this percentage changes to a minimum of 90% and an average of 97.050% problems identified by 15 users. Nielsen [44] advises that 5 participants is optimal for problem discovering, while Spool and Schroeder [45] support that problem-discovering relates to the complexity of tasks and 5 participants can only identify 35% of the problems in an interface. As Macefield [46] demonstrated there is no "one size fits all" solution; however, 5 to 10 participants is a sensible baseline range for problem discovery while comparative studies aiming at statistically significant results should have 10 to 12 participants. Furthermore, the length of the study should be taken into consideration. According to Baek et al [47], users participate in a design at the full inclusion level and the emancipatory level by cooperating with the researchers and developers or even carry out the design themselves over a long period of time. Taking into consideration the average age of the participants and the place of the study, the number of users can be considered satisfactory and beneficial for this study.

Limitations

There are some limitations in our study. The 3 most important are

- The adjusted protocol was modified during a long period with 1 user group. It should be tried on new groups to be confirmed and further adjusted.
- Gaining trust from the participants and also within the group of participants can lead to biased results from participants wanting to please the researchers or developers.
- A small steady group could after a while feel that the game is partly their creation, particularly when they see changes based on their feedback. This can make the users less critical.

Comparison With Prior Work

The players often bring their own context into game play and this should be reflected in exergames for elderly people [19]. The senior population, for instance, often has other preferences than the young when it comes to music and activities that would make a game enjoyable. Also, activities from the past that can trigger fond memories could make a good background for game stories, but as our example with the scythe shows, elderly people need to be involved to get the stories and activities correct.

When approaching the very old, one needs to be patient and spend the time that is required to gain trust, but tests and interviews will take longer, and less can be done at a time. Our experiences forming, evaluating, and adjusting the proposed protocol echo the findings of Redish and Chisnell [48] that recruiting and working with older adults requires special communication.

Questionnaires are found difficult to read and fill in. According to our experience, when given a paper questionnaire many will ask for help to read, explain, and write the replies. If the seniors are left alone filling them in, there are often many blanks and several replies that indicate that they have not understood the questions. Hayes et al [49] also confirm that seniors often have problems filling in quite simple questionnaires on their own, either feeling unable to do so or missing out on questions or information given. Questionnaires should therefore be filled in by a helper or in structured interviews. This could lead to biased results since they will not be anonymous, but we think that this is a smaller problem than not understanding the questions and one that can be taken into account when analyzing the results.

Iacono and Marti [50] point out how important it is to create an empathic and trusted relationship between participants and designers in participatory design with seniors and state that the role of the facilitator is crucial. Being in line both with our experience and the view of Iacono and Marti is that knowledge is not acquired once and for all by older adults, since they often forget recent events.

Conclusions

Involving seniors in the entire process can lead to many big and small changes that are essential to make good, safe, and fun games that the seniors will want to play and thus be motivated to exercise more. In this respect, involving senior end users when designing exergames for this group is essential. However, the UCD must be adjusted to suit this user group.

It is important to plan the sessions so as not to exhaust or confuse the participants, and each session should be short and should not cover too many aspects at once. It is also a good idea to leave time to perform the same tests or questions/interviews in several sessions in case many participants are absent at the first one. Also, questions should be formed with care and questionnaires should be short and either filled in using structured interviews or with a helper at hand.

Devoting time to seniors is a key element of the success of a UCD so that trust can be gained, communication can be established, and users' opinions can be registered. Thus, with some adjustments regarding time and tasks to perform, our initial protocol was useful and gave valuable results.

In the development of exergames for seniors applying UCD, all the different game elements should be taken into consideration during the design of exergames for seniors even if they seem to be obvious. Those elements include theme, movements, the user interface and interaction both with the games and the technology, colors, sounds, playability, etc.

Despite the fact that it might be considered a limitation, another reason for the useful feedback might be that a stable group of senior users participated in our study. They felt safe both with each other and with the researchers. The researchers gained their trust by spending much time with them playing, chatting, and sharing meals and learning the names of all participants.

It is clear from this research that best practices have been formed for UCD of serious games for older adults that look promising for researchers and developers and for facing societal challenges like active and healthy aging as well.

Acknowledgments

This work is supported by "GameUp: Game-Based Mobility Training and Motivation of Senior Citizens" (www.GameUpproject.eu), a project cofunded under the Ambient Assisted Living Joint Programme (REF. AAL-2011-4-090). All authors were key participants in the project and have participated in developing the protocol and the game and planning and performing the trials.

The authors would like to thank the seniors who participated in the biweekly meeting for UCD for over 2-and-a-half years and Vigdis Mellem, the person responsible for planning and arranging the meetings and calling each and every one before each gathering and also arranging with volunteers who would set up the room and serve the meal. These volunteers also deserve our gratitude.

Conflicts of Interest

None declared.

References

1. Kirk A, MacMillan F, Rice M, Carmichael A. An exploratory study examining the appropriateness and potential benefit of the Nintendo Wii as a physical activity tool in adults aged over 55 Years. Interact Comput. 2013. (1) p. 102-114 URL: https://iwc.oxfordjournals.org/content/25/1/102.short [WebCite Cache ID 6nPnFz7YN]
2. Wollersheim D, Merkes M, Shields N, Liamputtong P, Wallis L, Raynolds F, et al. Physical and psycosocial effects of Wii video game use among older women. Int J Emerging Technol Soc 2010;8(2):85-98.
3. Theng Y, Dahlan A, Akmal M, Myint T. An exploratory study on senior citizens' Perceptions of the Nintendo Wii: the case of Singapore i-CREATe '09. 2009 Presented at: 3rd International Convention on Rehabilitation Engineering & Assistive Technology; 2009; New York. [doi: 10.1145/1592700.1592712]
4. Anderson F, Annett M, Bischof WF. Lean on Wii: physical rehabilitation with virtual reality Wii peripherals. Stud Health Technol Inform 2010;154:229-234. [Medline: 20543303]
5. Konstantinidis ST, Fernandez-Luque L, Brox E, Kummervold PE. Seniors Exergaming 2.0: the role of social and motivational aspects on games for elderly's physical training through Web 2.0 techniques. 2014 Presented at: Proceedings of Medicine 2.0; 2014; Malaga p. 09-10.
6. Brox E, Konstantinidis, Evertsen G, Fernandez-Luque L, Rremartinez A, Oesch P, et al. GameUp: Exergames for mobility: a project to keep elderly active. 2016 Presented at: XIV Mediterranean Conference on Medical and Biological Engineering and Computing; 2016; Paphos, Cyprus p. 1219-1224.
7. Chao Y, Scherer YK, Wu Y, Lucke KT, Montgomery CA. The feasibility of an intervention combining self-efficacy theory and Wii Fit exergames in assisted living residents: A pilot study. Geriatr Nurs 2013;34(5):377-382. [doi: 10.1016/j.gerinurse.2013.05.006] [Medline: 23764366]
8. Williams MA, Soiza RL, Jenkinson AM, Stewart A. Exercising with computers in later life (EXCELL)—pilot and feasibility study of the acceptability of the Nintendo Wii Fit in community-dwelling fallers. BMC Res Notes 2010;3:238 [FREE Full text] [doi: 10.1186/1756-0500-3-238] [Medline: 20831836]
9. Evertsen G, Brox E. Acceptance of a targeted exergame program by elderly. 2015 Presented at: Proceedings from the 13th Scandinavian Conference on Health Informatics; 2015; Tromso, Norway p. 12-15.
10. Brox E, Luque L, Evertsen G, Hernandez JEG. Exergames for elderly: social exergames to persuade seniors to increase physical activity. 2011 Presented at: 5th International Conference on Pervasive Computing Technologies for Healthcare; 2011; Dublin, Ireland p. 546-549. [doi: 10.4108/icst.pervasivehealth.2011.246049]

11. Brox E, Evertsten G, Åsheim-Olsen H, Burkow T, Vognild L. Experience from long-term exergaming with elderly. In: Proceedings of the 18th International Academic Mindtrek Conference. New York: ACM; 2014:216-220. [doi: 10.1145/2676467.2676483]
12. Bird M, Clark B, Millar J, Whetton S, Smith S. Exposure to “Exergames” increases older adults' perception of the usefulness of technology for improving health and physical activity: a pilot study. JMIR Serious Games 2015;3(2):e8 [FREE Full text] [doi: 10.2196/games.4275] [Medline: 26614263]
13. Billis A, Konstantinidis E, Mouzakidis C, Tsolaki M, Pappas C, Bamidis P. A game-like interface for training seniors’ dynamic balance and coordination. IFMBE Proceedings 2010:691-694.
14. Konstantinidis EI, Billis A, Hlauschek W, Panek P, Bamidis PD. Integration of cognitive and physical training in a smart home environment for the elderly people. Stud Health Technol Inform 2010;160(Pt 1):58-62. [Medline: 20841650]
15. Jung Y, Li W, Gladys C, Lee K. Games for a better life: Effects of playing Wii games on the well-being of seniors in a long-term care facility. 2009 Presented at: Proceedings of the Sixth Australasian Conference on Interactive Entertainment; 2009; Sydney, Australia p. 0-5.
16. Rendon AA, Lohman EB, Thorpe D, Johnson EG, Medina E, Bradley B. The effect of virtual reality gaming on dynamic balance in older adults. Age Ageing 2012 Jul;41(4):549-552 [FREE Full text] [doi: 10.1093/ageing/afs053] [Medline: 22672915]
17. Brox E, Evertsen G, Åsheim-Olsen H, Hors-Fraile S, Browne J. Experience with a 3D Kinect exergame for elderly. 2015 Presented at: Proceedings of the 8th International Conference on Health Informatics; 2015; Lisbon, Portugal p. 12-15. [doi: 10.5220/0005165602310238]
18. Konstantinidis ST, Brox E, Kummervold PE, Hallberg J, Evertsen G, Hirche J. Online social exergames for seniors: a pillar of gamification for clinical practice. In: Novák D, Tulu B, Brendryen H, editors. Handbook of Research on Holistic Perspectives in Gamification for Clinical Practice. Hershey, PA: IGI Global; Oct 21, 2015:245-276. [doi: 10.4018/978-1-4666-9522-1.ch012]
19. van der Abeele AA, Van Rompaey RV. Introducing human-centered research to game design: designing game concepts for and with senior citizens. 2006 Presented at: CHI '06 Extended Abstracts on Human Factors in Computing; 2006; Montreal, Canada p. 1469-1474. [doi: 10.1145/1125451.1125721]
20. Gerling K, Schild J, Masuch M. Exergame design for elderly users: the case study of SilverBalance. 2010 Presented at: Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology; 2010; Taipei, Taiwan p. 66-69.
21. Ergonomics of human-system interaction—Part 210: Human-centred design for interactive systems. URL: https://www.iso.org/obp/ui/#iso:std:iso:9241:-210:ed-1:v1:en [accessed 2016-12-16]
22. Karat J, Karat CM. The evolution of user-centered focus in the human-computer interaction field. IBM Syst J 2003;42(4):532-541. [doi: 10.1147/sj.424.0532]
23. Sebe N. Human-centered computing. In: Handbook of Ambient Intelligence and Smart Environments. New York: Springer; 2010:349-370. [doi: 10.1007/978-0-387-93808-0_13]
24. Proffitt R, Lange B. User centered design and development of a game for exercise in older adults. Int J Technol Knowl Soc 2012;8(5):112.
25. van der Weegen S, Verwey R, Spreeuwenberg M, Tange H, van der Weijden T, de Witte WL. The development of a mobile monitoring and feedback tool to stimulate physical activity of people with a chronic disease in primary care: a user-centered design. JMIR Mhealth Uhealth 2013;1(2):e8 [FREE Full text] [doi: 10.2196/mhealth.2526] [Medline: 25099556]
26. Vredenburg K, Mao J, Smith P, Carey T. A survey of user-centered design practice. 2002 Presented at: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems; 2002; Minneapolis, MN p. 3460-3478. [doi: 10.1145/503376.503460]
27. Gregor P, Newell A, Zajicek M. Designing for dynamic diversity: interfaces for older people. 2002 Presented at: Proceedings of the 5th international ACM conference on Assistive technologies; 2002; Edinburgh, UK p. 151-156. [doi: 10.1145/638249.638277]
28. Thimbleby H. Understanding user centred design (UCD) for people with special needs. In: Miesenberger K, editor. Computers Helping People with Special Needs. Berlin: Springer; 2008.
29. Zajicek M. Successful and available: interface design exemplars for older users. Interact Comput 2004:411-430. [doi: 10.1016/j.intcom.2004.04.003]
30. Billis A, Konstantinidis E, Ladas A, Tsolaki M, Pappas C, Bamidis P. Evaluating affective usability experiences of an exergaming platform for seniors. Biomed Eng 2011:1-4. [doi: 10.1109/IWBE.2011.6079048]
31. Dickinson A, Arnott J, Prior S. Methods for human-computer interaction research with older people. Behav Inf Technol 2007;26(4):343-352. [doi: 10.1080/01449290601176948]
32. Holt B. Creating senior-friendly Web sites. Issue Brief Cent Medicare Educ 2000;1(4):1-8. [Medline: 11817407]
33. AgeLight. Interface Design Guidelines for Users of all Ages. 2001. URL: http://www.agelight.com/webdocs/designguide.pdf [accessed 2016-02-15] [WebCite Cache ID 6fJZssXUM]

34. Kurniawan S, Zaphiris P. Research-derived Web design guidelines for older people. 2005 Presented at: Proceedings of 7th international ACM SIGACCESS Conference on Computers and Accessibility; 2005; Baltimore, MD p. 129-135. [doi: 10.1145/1090785.1090810]
35. National Institute on Aging, National Library of Medicine. Making your Web site senior friendly: a checklist. 2002. URL: https://www.nlm.nih.gov/pubs/checklist.pdf [accessed 2016-02-15] [WebCite Cache ID 6fJaI60tL]
36. Bamidis PD, Gabarron E, Hors-Fraile S, Konstantinidis E, Konstantinidis S, Rivera O. Gamification and behavioral change: techniques for health social media. In: Syed-Abdul S, Gabarron E, Lau A, editors. Participatory Health Through Social Media. London: Elsevier; Jun 17, 2016:112-135.
37. Chrisnell D, Redish J. Designing web sites for older adults: expert review of usability for older adults at 50 Web sites. AARP. 2005. URL: http://www.redish.net/images/stories/PDF/AARP-50Sites.pdf [accessed 2016-12-16] [WebCite Cache ID 6mo2iujhA]
38. Kurniawan S, King A, Evans D, Blenkhorn P. Personalising Web page presentation for older people. Interact Comput 2006 May;18(3):457-477. [doi: 10.1016/j.intcom.2005.11.006]
39. Fidgeon T. Usability for Older Web Users. WebCredible. 2006. URL: http://www.webcredible.com/blog/usability-older-web-users/ [accessed 2016-02-15] [WebCite Cache ID 6fJbSkwzL]
40. Arch A, Abou-Zahra S. Developing websites for older people: how web content accessibility guidelines (WCAG) 2.0 applies. Web Accessibility Initiative. 2010. URL: https://www.w3.org/WAI/older-users/developing.html [accessed 2016-02-15] [WebCite Cache ID 6fJbgt5SI]
41. Awad M, Ferguson S, Craig C. Designing games for older adults: an affordance-based approach. 2014 Presented at: IEEE 3nd International Conference on Serious Games and Applications for Health (SeGAH); 2014; Rio de Janeiro, Brazil URL: http://doi.org/10.1109/SeGAH.2014.7067103 [doi: 10.1109/SeGAH.2014.7067103]
42. Hors Fraile S, Browne J, Brox E, Evertsen G. Suitability analysis of commercial open-source driven motion sensor devices applied to exergames for the elderly. Ambient Assisted Living Forum Eindhoven 2012.
43. Faulkner L. Beyond the five-user assumption: benefits of increased sample sizes in usability testing. Behav Res Methods Instrum Comput 2003 Aug;35(3):379-383. [Medline: 14587545]
44. Nielsen Norman Group. Why You Only Need to Test With 5 Users. 2000. URL: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/ [accessed 2016-11-29] [WebCite Cache ID 6mOEaiOUa]
45. Spool J, Schroeder W. Testing web sites: five users is nowhere near enough. 2001 Presented at: CHI '01 Extended Abstracts on Human Factors in Computing Systems; 2001; Seattle. [doi: 10.1145/634067.634236]
46. Macefield R. How to specify the participant group size for usability studies: a practitioner's guide. J Usability Studies 2009;5(1):34-45 [FREE Full text]
47. Baek EO, Cagiltay K, Boling E, Frick T. User-centered design and development. In: Spector JM, Merrill MD, van Merrienboer JJ, Driscoll MF, editors. Handbook of Research on Educational Communications and Technology, Third edition. London: Routledge; 2008:659-570.
48. Redish J, Chisnell D. Designing web sites for older adults: a review of recent research. AARP. 2004. URL: http://www.redish.net/images/stories/PDF/AARP-LitReview2004.pdf [accessed 2016-02-15] [WebCite Cache ID 6fJcYH312]
49. Hayes V, Morris J, Wolfe C, Morgan M. The SF-36 health survey questionnaire: is it suitable for use with older adults? Age Ageing 1995 Mar;24(2):120-125. [Medline: 7793333]
50. Iacono I, Marti P. Engaging older people with participatory design. 2014 Presented at: Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational; 2014; Helsinki, Finland p. 859-864. [doi: 10.1145/2639189.2670180]

Abbreviations

UCD: user-centered design

Edited by G Eysenbach; submitted 22.06.16; peer-reviewed by ML Bird, M Immonen, C Giraud-Carrier; comments to author 25.07.16; revised version received 30.11.16; accepted 30.11.16; published 11.01.17.

Please cite as:
Brox E, Konstantinidis ST, Evertsen G
User-Centered Design of Serious Games for Older Adults Following 3 Years of Experience With Exergames for Seniors: A Study Design
JMIR Serious Games 2017;5(1):e2
URL: http://games.jmir.org/2017/1/e2/
doi:10.2196/games.6254
PMID:28077348

Publisher:
JMIR Publications
130 Queens Quay East.
Toronto, ON, M5A 3Y5
Phone: (+1) 416-583-2040
Email: support@jmir.org