A modifiable virtual reality game for neurological physiotherapy – Multiprofessional development and pilot testing

1st Anja Poberznik
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
anja.poberznik@samk.fi

2nd Jenni Huhtasalo
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
jenni.huhtasalo@samk.fi

3rd Taina Jyräkoski
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
taina.jyrakoski@samk.fi

4th Sanna Seppä
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
sanna.seppa@samk.fi

5th Jani Lahti
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
jani.lahti@samk.fi

6th Ali Tavakoli
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
ali.2.tavakoli@samk.fi

7th Johanna Virkki
Tampere Institute of Advanced Study
Tampere University
Tampere, Finland
johanna.virkki@tuni.fi

8th Sari Merilampi
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland
sari.merilampi@samk.fi

***Abstract*— Serious games and virtual reality are promising tools for future rehabilitation. They represent solutions for promoting self-care and for motivating the rehabilitees. However, their wider adoption requires experience and research information from both the rehabilitators themselves and experts in the field. The aim of this study is to develop a prototype physiotherapy virtual reality game in multiprofessional collaboration and to learn about the best practises leading into positive user experience. This paper emphasizes the game development process, the Whac-A-Physio game prototype itself and the preliminary user experiences utilizing a co-design approach. It is a basis for future studies with higher number of participants. The physiotherapy professionals were interested in developing the game in a multidisciplinary group and motivated to adopt it. The developed Whac-A-Physio game prototype was subsequently piloted in two physiotherapy clinics. The feedback was obtained from the physiotherapists by semi-structured interviewing. The physiotherapists found the game suitable for upper limb therapy, balance, and coordination training. The game presented a valuable motivational tool for their clients, improving their sense of ability and inclusion, and was thus considered a good addition to the conventional therapy.**

Keywords—physical ability, virtual reality, rehabilitation, serious game development, co-design

I. Introduction

With increasing rehabilitation patient volume and decreasing reimbursement rates, clinicians, including physiotherapists are required to produce favourable outcomes with limited resources and time [1]. As the areas of expertise in physiotherapy are growing and expanding, the work with human functionality and disability demands the interaction with various areas of knowledge [2]. New technology can open doors for new and non-traditional approaches in physiotherapy, which may greatly benefit both therapists and patients.

Serious games (games combining entertainment and useful content, such as educational or rehabilitation elements) are one promising solution related to motivating people for rehabilitation and self-care. Serious games have been developed for both physical [3–7] and mental or cognitive well-being [8–10]. Although serious games can be a valuable option for both prevention and rehabilitation, further research is needed to evaluate the factors leading into motivation and engagement as well as successful therapy results.

Virtual reality (VR) is a simulated experience, which can be similar or completely different from the real world, dependent on how immersive the experience is. Interaction with the simulated environment allows the user to receive continuous, immediate feedback related to performance. VR is widely used in entertainment, business, and education but also in healthcare. Also, physiotherapy clients could benefit from VR in various ways. According to previous studies, patients can be, for example, encouraged to be active and overcome the fear of pain [10–14]. In addition, research suggests that virtual reality can have a positive effect on rehabilitation, such as recovery of upper extremity functions, hand motor control, cognitive impairment, and balance [15–19].

Although the previous studies are encouraging, there is a lack of commercial VR games developed for physiotherapy. One reason is the challenges related to serious games development. To develop a useful game, the game should contain embedded therapeutic content to bring the benefit as well as entertaining/motivation component to engage users. Additionally, the game needs to be accessible to the end users and thus service models may differ from the traditional game distribution channels [20]. The user groups in therapy are also heterogeneous with different functional abilities, including special user groups. Bierre with colleagues [21] presented various issues that make the special user group game play challenging. These are: inability to follow a storyline, inability to complete a puzzle or task, inability to determine how a game is played, inability to use adaptive hardware, and player's character gets killed/injured repeatedly in the game which is very demotivating [21]. In this study, a co-design approach of a

multidisciplinary development team is taken to tackle these before the mentioned game development challenges. The aim is to identify the key elements in the game and game development process to support successful therapy game implementation.

This paper is organized as follows: This brief Introduction Chapter is followed by Chapter II, which introduces the game development co-design process. Chapter III introduces the developed game prototype, and it is followed by Chapter IV, which describes the initial user experience testing of the developed game. Chapter V discusses the results. Finally, the conclusions of this study are gathered in Chapter VI.

II. Co-Design Approach in Game Development

The design process in this study followed a co-design approach [22], which refers to the collective creativity of a multidisciplinary group of people. Co-designing is a democratic and open mindset, which questions hierarchical power structures involving all parties in the design and demanding mutual learning with planners, stakeholders, and actors [23]. Through user proxies, too early prototypes do not cause frustration in actual end users, but the idea can be visualized, and the useful characteristics identified [24]. Physiotherapy specialists were used as user proxies in this study.

First phase of the co-design process started with a group discussion in which six persons participated. The group included three physiotherapy specialists/end-user proxies, two technology providers, and a service designer/researcher. The reason for involving the end-user proxies and not the clients from the beginning was due to very heterogeneous client groups of the physiotherapy clinic involved in the development process. This approach allows the physiotherapy professionals to identify multiple client groups which might benefit from the game after further adjustments. The discussion started with technology knowledge transfer to describe the possibilities of VR technology. This was done through simple demonstrations with existing commercial VR games on various VR sets, such as Beat Saber on Oculus Quest 1, a Fishing game on Oculus GO and NVIDIA VR Funhouse on Oculus Rift. This followed by ideation discussion in which the multidisciplinary group identified the key needs of the physiotherapy provider: improving the immersion in training, providing new and "trendy" tool to make more variation in long-term customer relationship and to get an objective addition to assess the therapy outcomes. The physiotherapists also gave a description on the overall characteristics of their clients and their rehabilitation need as well as their ability to function. Based on this discussion, a game idea was produced for a modifiable upper limb training game for improving range of motion, coordination, reaction speed and balance that can be affected by a trauma or disease. Mobile VR glasses were identified to be the best equipment for the game in this use context.

The second phase of the co-design was an early prototype development and testing with the physiotherapy professionals involved in the first phase as well. In the second group event, the early prototype was introduced and the next steps in the development were identified. The focus was especially in defining which elements in the game and game play must be adjustable to meet the need of heterogeneous group of clients. In real use, these parameters are then adjusted by the physiotherapy professional based on the client needs. The third phase included another group discussion, which was organized to introduce and test the improved prototype. After the event the improved prototype was given in use for the physiotherapy professionals at their own work. The third event also included a training on how to do the adjustments as well as how to install updates to the game remotely.

This was followed by a pilot period in the physiotherapy clinic during which also the therapy clients provided feedback to the physiotherapy professionals about the game. Small improvements such as changing the position or appearance of the game elements and adding the adjustable parameters were still made according to the feedback, and the updated version of the game was sent after each of the three improvement cycles for the piloting organization. In addition to the group events, active e-mail discussion and phone conversations were used to guarantee the user-centred focus in the development. During this first pilot period, especially adjustable parameters were refined, and the modifications were made to the latest prototype, which is used in the pilots discussed in this article with other physiotherapy professionals who were not involved in the game development.

III. Whac-A-Physio Game Prototype

Whac-A-Physio game is based on the popular Whac-A-Mole game. A typical Whac-A-Mole game is played on a machine consisting of a waist-level cabinet with a play area and display screen, and a large, soft, black mallet. Five holes in the play area top are filled with small plastic moles, which pop up randomly. Points are scored by whacking each mole as it appears. The faster the reaction the higher the score [25]. Whac-A-Physio game differs from the original game in two main aspects. Firstly, Whac-A-Physio is played in virtual reality using a VR headset Oculus Quest (or Oculus Quest 2) and two controllers. Secondly, instead of moles popping out of the holes, Whac-A-Physio game uses virtual white 3D square tiles, which colour into either red or blue, thus indicating the tile that must be whacked.

To play the game, the player must wear the VR headset and hold the right controller in the right hand (shown red in the virtual world) and the left controller in the left hand (shown blue in the virtual world). Upon entering the game menu, the player can select the suitable settings and determine the size of the play area (Fig. 1). There are no standard game settings to begin the game to quarantee consideration of the person's needs and adjustments. The player can interact with the game in two ways: by extending the arm that holds the controller far enough to touch the virtual button or addressing the virtual button using a virtual laser by pressing the trigger button on the controller with index finger. The game starts upon selecting the Start button. A board with white square tiles arranged in columns and rows appears in front of the player. The white tiles colour themselves either in blue or red in random order (Fig. 2). The player must address the coloured tiles with the corresponding controller (red tile with the right controller/laser, blue tile with the left controller/laser). Each correctly addressed tile brings a point. The game ends once the player has hit the pre-determined number of tiles.

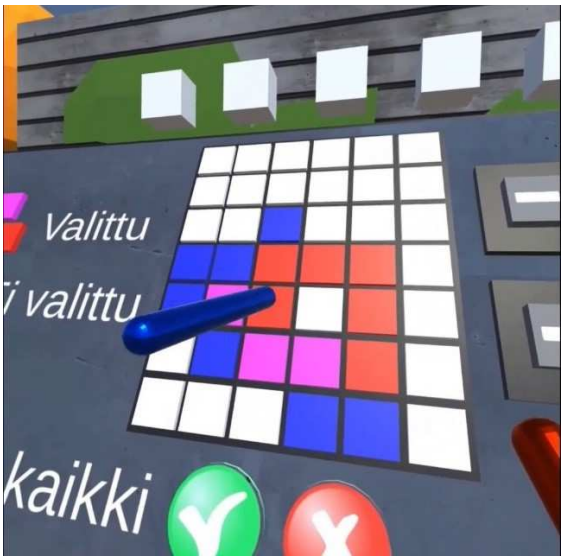

Fig. 1. Choosing the size of the play area in the game menu.

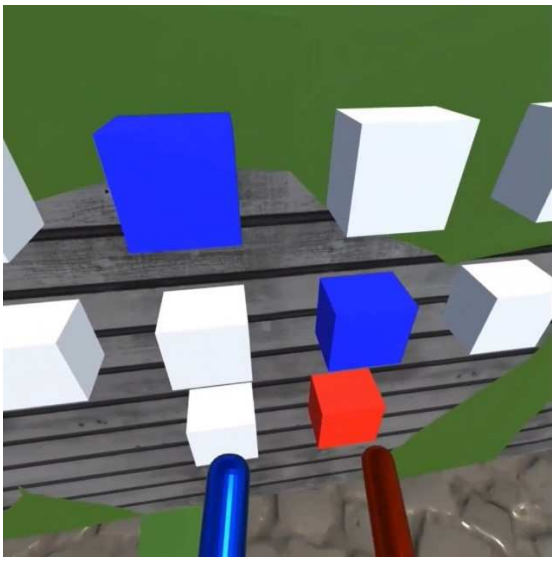

Fig. 2. Gameplay with blue and red coloured tiles.

The game is accompanied by graphics, music, and audio cues. Game environment resembles a relaxing forest environment with trees and animals. During the gameplay, there is no music to distract the player from audio cues, just distant bird singing. Audio and music can be adjusted or disabled in the game menu or by adjusting the volume of the VR device. The performance results are seen as soon the player has completed the game. The results display reaction time (average time between hits), game duration, points achieved and "combo". Combo refers to consecutive correct hits without missing tiles or hitting incorrect tiles. To maintain the positive playing spirit, there are no deducting points for incorrect attempts.

To increase the usability of the game, several settings can be adjusted either by the therapist or the patient. These are: the size of the play area, the size of the tiles, the duration of the game (by choosing the number of the tiles that appear in the game), the duration (in seconds) of each tile colouring up before vanishing, and the time (in seconds) between the consecutive appearance of the tiles. There is also an option of using a laser for pointing. If this option is enabled, the player does not have to extend their arms so far to reach the tiles or change the settings. The game can be played in standing or sitting, using either both upper extremities (and thus two controllers) or just one.

IV. Piloting and Results

Whac-A-Physio game prototype was tested in two physiotherapy clinics, which were not the same as the clinic involved in the development process. The physiotherapists (PTs) in these clinics tested the game with their clients. The clients' diagnoses and age were diverse with the youngest being nine years old and the oldest 54.

A. Methodology

The feedback from the PTs (N=7) was obtained by semi-structured interviewing. The questions concerned the use of the game itself (ease of use, usefulness, learnability, flexibility) and the effect of the prototype on their job performance, including questions about what kind of challenges the PTs had encountered when playing the game or setting it up, and whether the use was perceived as time consuming. In addition, there was a general question about the use of welfare technology in rehabilitation and benefits of this game as part of rehabilitation. It was also inquired, what kind of clients the PTs think would benefit from the game and who would not.

B. Results

Results obtained from the semi-structured interviews are presented next by summarizing the PTs comments. Often, the PTs did not distinguish between the VR technology (VR set) and the game itself, and they referred to both in their answers.

The feedback was versatile, but generally positive. All participants except one informed the prototype to improve the quality of their work even slightly, although almost half felt having less control over their job (the physical rehabilitation). All seven participants felt the prototype rather easy to use (one had "neutral" opinion on this) and easy to learn, although there were also comments about the learning to take some mental effort. Some critique was given about the inflexibility to interact with the prototype (especially changing the settings). Every participant felt positive about the prototype's usefulness in their job (providing rehabilitation services) and even making their job somewhat easier. Opinions about the prototype making their job more effective were more heterogenous and less convincing. Half of them felt the job to become somewhat more effective or the prototype to improve their performance whereas the rest did not consider the prototype to make the job more effective. These findings are next discussed in more detail.

PTs utilized the Whac-A-Physio game in rehabilitation with heterogenous user groups considering functional ability, gender and age. Adults were excited about their own performance in terms of mobility and ease of use of the game. The game was utilized from both a standing position and a wheelchair (Fig. 3). Even when played from a wheelchair, the game worked well, the demarcation of the game area had been functional, and the adjustable size of the play area and the speed of the game had served individual rehabilitation. The PTs found the use of the VR device and the game quite easy. Setting up the game was relatively quick, 5-10 minutes depending on a client and the glasses were easily placed on the client´s head. Casting the game on

the computer screen made the guiding and participation easier. This allowed some clients to be active from the beginning while they were able to set the game themselves. Casting did not function well every time and it caused image delays. Because the game was easy to use, it also made a person who was critical of technology enjoy playing it. However, as the game is simple, some children became bored while playing and they might had benefitted from different variations in the game.

Fig. 3. Whac-A-Physio can be played in standing or sitting (e.g., in a wheelchair).

The PTs found that adjusting the settings after they had first worn the glasses themselves and then moved them to the client was sometimes difficult. Meanwhile the glasses were moved the settings could change and the client might not know what to do. The PTs suggested there should be a tablet where all the settings could be adjusted while the client is already using the headset. They reported problems in handling the controllers and operating the buttons, which also affected playing the game.

Whac-A-Physio enabled the clients to practice both the body balance and coordination as well as effective training of upper limb movements. Clients were able to exercise their range of motion in upper limbs and neck almost without noticing. In addition, the game was perceived as very motivating. The PTs were pleased with the game when using it with the neurological clients and those who sit in a wheelchair. The game granted new experiences, as well as produced a sense of ability and inclusion for the client. Clients with poor cognition or localized musculoskeletal problems such as with fingers or in the neck and shoulder area would not benefit from this kind of a training, according to the PTs.

The PTs believed the game serves well as part of rehabilitation and it adds motivation to the training. It also has benefits for weight shifting and balance when trained in upright position and sitting even though the game requires more upper limb movements. In their opinion, rehabilitative training is often quite narrow and limited, which is why gamification complements and diversifies the offered physiotherapy.

V. Discussion

Whac-A-Physio game encompasses upper limb movements through anterior shoulder flexion and abduction. At the same time, it promotes upper body rotations, coordination of movements, and challenges the player's (client's) balance in both standing and sitting. It is desirable that the game is inclusive of users with lower limb paralysis as it was proven to be played by people using wheelchairs. Game settings are crucial for successful implementation of the game, as the game should fit various abilities of the end users. Easy customisation that can be achieved by both physiotherapists and the clients is a benefit in the game development. In case of poor functioning of the upper limbs, the therapist can adjust the settings suitable for the client's range of motion. The game can be set to use only one upper limb, for example in case of one side paralysis (hemiplegia) or amputations. In this case, only one controller equaling either red or blue colour is used. The physiotherapist's professional assessment of the client should always determine whether playing the game would benefit the client or not. Therefore, a good understanding of the game and its adjustment possibilities are crucial for the physiotherapist to have. Game casting (mirroring) on a computer or a tablet enables the therapist to see what is happening in the virtual world and can thus facilitate the client more accurately.

This kind of a game can be a part of intentional training in rehabilitation and complement the therapy. Especially when discussing about long-term customer relationship, motivational matters and versatile ways of training are important. Playing Whac-A-Physio could be an occasional part of a physiotherapy session, complementing other therapeutic modalities, and played for a short duration, also depending on the client's motivation. VR-rehabilitation has not been proven superior to any other therapy. Instead, it was evaluated to be as effective as other therapies if it is easy to use for the therapist and possible to be tailored for the clients. So far, the studies recommend the application of VR gamification as an adjacent method to the conventional therapy methodologies [26–29].

No adverse effects were reported by the PTs, although it is known that virtual reality might cause eye fatigue, dizziness, headache, and motion sickness, especially in full-immersion VR games with a moving background [30]. The PTs did not find the game (or VR device) suitable for people with neck issues. This correlates with literature, where prolonged use of the VR headset might increase the burden on the cervical spine in some individuals, risking greater neck strain [31]. It is preferable from the perspective of reducing adverse effects that only fixed-background full-immersion VR games be used in rehabilitative interventions [30]. Whac-A-Physio game has a static background and thus low-immersion, which appears to be more suitable for the rehabilitation.

The game is only a prototype and thus has a lot of space for improvement. Although the game settings can be adjusted to increase the challenges in the playing, more difficulty levels can be added to the existing prototype to maintain the player's motivation. It is also well notable that such game is not suitable for everyone. Children with attention deficit disorder might find it difficult to concentrate on playing the game for sustained time, so shorter play times combined with other physical activities should be considered. It is the physiotherapist's professional skill to recognize whether their client would benefit from playing this game or not. Our future work is to further develop different game versions for various user groups and special needs.

The authors are aware that it is not enough to hand out the VR device with the game to the therapists. Technical staff should provide a training to the therapists on how to use the VR device, set up the game, adjust the settings and cast it on another device as these all determine success in the implementation of the gamified therapy. The training should also contain information on VR indications and contraindications, and possible adverse effects. In addition, technical staff should offer technical support and be reachable for any technical difficulties that might occur during the period of the game use. These points are all part of a good service design.

Co-designing was based on continuous and open communication and feedback on both sides. The game´s developers have received development ideas from both physiotherapists and their clients. According to the physiotherapists who have been involved in the process, the co-designing has been rewarding. The ideation, co-designing and validation were carried out both remotely in various meetings and in practice together with rehabilitators. An open atmosphere has been an essential factor in promoting co-operation and it is the main theme of co-design. Whac-A-Physio game is a great example of co-design. Without the involvement of all parties in the game development, many important issues could have been overlooked. In addition to game development, collaboration work extended to a variety of devices, such as game controllers. A need emerged for accessible VR controllers that can be used by clients with poor handgrip strength or spasticity in their hands or fingers. Customizable VR controller add-ons can be easily designed for a specific use utilizing 3D-printing technology. Apart from Whac-A-physio, 3D-printed VR controller add-ons can be used also for other VR games. Possibilities of 3D-printed add-ons for the VR controllers that can be worn on the lower limbs can also be explored.

The number of participants in the study was low. However, the aim of the study was not to make far reaching conclusions, as this would require a higher number of participants, but rather use the thematic questions as they are essential for the product development. The study offers preliminary results towards the acceptance of the Whac-A-Physio game prototype and serves as a basis for our future work where we will focus on the game adoption by the patients and larger scale research on the usability and user experiences.

VI. Conclusion

As outlined above, serious games and virtual reality will play a major role in future rehabilitation. These technologies can increase the sense of ability, inclusion, and participation. It is important to educate the physiotherapists as well as other healthcare professionals on the benefits of the serious games and involve them in the game development already at the ideation stage. Co-design process with the physiotherapy clinic has opened further collaboration opportunities. Several possibilities of accessible VR game controllers using 3D printing technology were discussed. These can be researched and tested in the future collaboration. Providing solely the technology to the end users is not sufficient. Training, instructions, and technical support should be considered, too. There is also a need for co-design and service design thinking in the future work. Co-design allows us to explore a range of options and rely on the structured process of prototyping and testing to develop our work together. Only co-design combined with service design thinking makes innovation and new ways of thinking possible. Such forms of working always require multidisciplinarity and crossing over the areas of expertise. Hence, multisectoral and multidisciplinary working in such development processes are crucial to successful outcome.

Acknowledgment

The research was part of Satakunta DigiHealth project, funded by the Regional Council of Satakunta (ERDF) and municipalities in the area.

References

[1] J. G. Owens, M. R. Rauzi, A. Kittelson, J. Graber, M. J. Bade, J. Johnson, and D. Nabhan, How new technology is improving physical therapy, Current reviews in musculoskeletal medicine 13.2, 2020, pp. 200-211. doi: 10.1007/s12178-020-09610-6.

[2] A. R. Araujo, I. C. D. Perdigão, S. G. F. Amaral, T. V. Rodrigues, C. A. P. da Silva Martins, and P. S. S. Maciel, Technologies for rehabilitation: Problems and opportunities in the Physiotherapy Clinic at PUC Minas-Brazil, in: IEEE Global Humanitarian Technology Conference GHTC, PUC Minas - Brazil, 2014, pp. 402-407.

[3] H. Nauta and T. A. M. Spil, Change your lifestyle or your game is over: The design of a serious game for diabetes, in: Proceedings of the IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH), Braga, Portugal, 2011, pp. 1-7.

[4] C. Ferreira, Gamification of stroke rehabilitation exercises using a smartphone, in: Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare ICST, Oldenburg, Germany, 2014, pp. 282-285.

[5] T. Martins, V. Carvalho, and F. Soares, A serious game for rehabilitation of neurological disabilities: Premilinary study, in: Proceedings of the IEEE 4th Portuguese Meeting on Bioengineering (ENBENG), Porto, Portugal, 2015, pp. 1-5.

[6] R. N. Madeira, L. Costa, and O. Postolache, PhysioMate-Pervasive physical rehabilitation based on NUI and gamification, in: Proceedings of the International Conference and Exposition on Electrical and Power Engineering (EPE), Iasi, Romania, 2014, pp. 612-616.

[7] D. Deponti, D. Maggiorini, and C. E. Palazzi, Smartphone's physiatric serious game, in: Proceedings of the IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH), Braga, Portugal, 2011, pp. 1-8.

[8] A. Miloff, A. Marklund, and P. Carlbring, The challenger app for social anxiety disorder: New advances in mobile psychological treatment, Internet Interventions 2.4, 2015, pp. 382-391.

[9] T. Martins, V. Carvalho, F. Soares, and M. F. Moreira, Serious game as a tool to intellectual disabilities therapy: Total challenge, in:

Proceedings of the IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH), Braga, Portugal, 2011, pp. 1-7.

[10] C. Chang, A. Hinze, J. Bowen, L. Gilbert, and N. Starkey, Memory: mobile memory assistant for people with traumatic brain injury, International Journal of Human-Computer Studies 117, 2018, pp. 4-19.

[11] B. Spiegel, G, Fuller, M. Lopez, T. Dupuy, B. Noah, A. Howard, M. Albert, V. Tashjian, R. Lam, J. Ahn, and F. Dailey, Virtual reality for management of pain in hospitalized patients: A randomized comparative effectiveness trial, PloS one 14.8, 2019: e0219115.

[12] J. S. Thomas, C. R. France, M. E. Applegate, S. T. Leitkam, and S. Walkowski, Feasibility and safety of a virtual reality dodgeball intervention for chronic low back pain: a randomized clinical trial, The Journal of Pain, 17.12, 2016, pp. 1302-1317.

[13] T. Jones, T. Moore, J. Choo, The impact of virtual reality on chronic pain, PloS one 11.12, 2016: e0167523.

[14] J. W. Vlaeyen and S. J. Linton, Fear-avoidance and its consequences in chronic musculoskeletal pain: a state of the art, Pain 85.3, 2000, pp. 317-332.

[15] M. O. Powell, A. Elor, M. Teodorescu, and S. Kurniawan, Openbutterfly: Multimodal rehabilitation analysis of immersive virtual reality for physical therapy, American Journal of Sports Science and Medicine 8.1, 2020, pp. 23-35.

[16] F. Carneiro, R. Tavares, J. Rodrigues, P. Abreu, and M. T. Restivo, A gamified approach for hand rehabilitation device, International Journal of Online Engineering 14.1, 2018.

[17] A. Elor, M. Teodorescu, and S. Kurniawan, Project star catcher: A novel immersive virtual reality experience for upper limb rehabilitation, ACM Transactions on Accessible Computing (TACCESS) 11.4, 2018, pp. 1-25.

[18] I. Afyouni, F. U. Rehman, A. M. Qamar, S. Ghani, S. O. Hussain, B. Sadiq, and S. Basalamah, A therapy-driven gamification framework for hand rehabilitation, User Modeling and User-Adapted Interaction 27.2, 2017, pp. 215-265.

[19] J. Hwang and S. Lee, The effect of virtual reality program on the cognitive function and balance of the people with mild cognitive impairment, Journal of physical therapy science 29.8 (2017): 1283-1286.

[20] S. Merilampi, A. Koivisto, M. Leino, N. Pombo, V. Felizardo, J. Lu, A. Poberznik, and J. Virkki, Implementing Mobile Games into Care Services - Service Models for Finnish and Chinese Elderly Care, Information,10(2), 2019, p. 55.

[21] K. Bierre, J. Chetwynd, B. Ellis, D. M. Hinn, S. Ludi, and T. Westin, Game not over: Accessibility issues in video games, in: Proceedings of the Third International Conference on Universal Access in Human Computer Interaction, Mahwah, NJ , 2005, pp. 22-27.

[22] E. Sanders and P. Stappers, Co-creation and the new landscapes of design, Co-Design 4.1 (2008): pp. 5-18.

[23] A. Fuad-Luke, Design Activism: Beautiful Strangeness for a Sustainable World, Routledge, 2009.

[24] S. Merilampi, A. Koivisto, and A. Sirkka, Designing serious games for special user groups—design for somebody approach, British Journal of Educational Technology 49.4 (2018): pp. 646-658.

[25] Whac-A-Mole. URL: https://en.wikipedia.org/wiki/Whac-A-Mole

[26] E. Wiley, S. Khattab, and A. Tang, Examining the effect of virtual reality therapy on cognition post-stroke: a systematic review and meta-analysis, Disability and Rehabilitation: Assistive Technology (2020): pp. 1-11

[27] P. Dias, R. Silva, P. Amorim, J. Lains, E. Roque, I. Serôdio, and B. S. Santos, Using virtual reality to increase motivation in poststroke rehabilitation, IEEE computer graphics and applications 39.1 (2019): pp. 64-70.

[28] A. Aminov, J. M. Rogers, S. Middleton, K. Caeyenberghs, and P. H. Wilson, What do randomized controlled trials say about virtual rehabilitation in stroke? A systematic literature review and meta-analysis of upper-limb and cognitive outcomes, Journal of neuro engineering and rehabilitation 15.1 (2018): pp. 1-24.

[29] D. Rand, N. Givon, H. Weingarden, A. Nota, and G. Zeilig, Eliciting upper extremity purposeful movements using video games: a comparison with traditional therapy for stroke rehabilitation, Neurorehabilitation and neural repair 28.8 (2014): pp. 733-739.

[30] S. Park and G. Lee, Full-immersion virtual reality: Adverse effects related to static balance, Neuroscience letters 733 (2020) 134974. doi: 10.1016/j.neulet.2020.134974.

[31] Oregon State University: Virtual reality, real injuries: How to reduce physical risk in VR. ScienceDaily, 2020. URL: www.sciencedaily.com/releases/2020/01/200108092448.htm