DEVELOPMENT OF BIOFEEDBACK-BASED VIRTUAL REALITY THERAPIES, RESEARCH OF EFFICIENCY AND PRESENCE

Propositions of the doctoral PhD dissertation

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1 IMPORTANCE OF THE RESEARCH TOPIC

Biofeedback-based Virtual Reality (VR) therapies are significant due to their potential impact on rehabilitation. The development and use of VR-based serious games for activities such as breathing exercises and memory training address critical areas in modern healthcare, particularly for individuals affected by post-COVID syndrome, memory problems, and pulmonary disorders. VR-based therapies can help to move towards a more patient-centered rehabilitation [1-2]. This interactive method supports therapy and can lead to better rehabilitation outcomes. Traditional rehabilitation methods often lack the engaging and immersive features needed to keep patients interested, while VR bridges this gap as an effective tool. The value of this research is particularly evident in the field of cognitive and memory rehabilitation. Cognitive impairments that affect daily life require tailored strategies for memory enhancement, learning facilitation, and social interaction. Several studies demonstrate the potential of VR-based adaptations of cognitive assessment, highlighting VR's capacity for more engaging and ecologically valid evaluations compared to conventional neuropsychological methods [3–25]. The potential of VR in pulmonary condition rehabilitation is also highlighted, as breathing exercises can be practice with it help, aiding both physical recovery

and stress reduction [26-34]. Furthermore, research into comparing various visualization displays in rehabilitation may lead to improved guidelines for the effective use of VR technology, optimizing efficacy and user experience. The focus on identifying cost-effective solutions and understanding barriers like user discomfort, cybersickness and accessibility is critical to ensure that these technologies benefit a wider range of individuals. VR in home-based therapy can extend patient care beyond clinics, reducing strain on healthcare providers and promoting patient independence. The primary goal of this dissertation is to identify the best practice in Virtual Reality rehabilitation.

2 MOTIVATION AND AIMS

The use of VR in rehabilitation represents a promising but underexplored area of research. As technology advances, the integration of innovative methods into healthcare has become crucial. This Ph.D. dissertation is driven by the need in modern healthcare for accessible, personalized rehabilitation treatments, as traditional methods often lack the effectiveness and efficiency to meet patients' diverse, complex needs. Virtual Reality therapies can form a potential avenue for addressing these challenges by offering scalable, patient-centered solutions to traditional therapeutic interventions. Unlike traditional methods, VR can reproduce engaging and immersive environments that transform traditional rehabilitation tasks into dynamic and engaging experiences. The use of VR can potentially make rehabilitation enjoyable and interactive, which is very important for maintaining patient participation for as long as possible, thereby leading to better health outcomes. Biofeedback associated with Virtual Reality increases the level of personalization and the specificity of therapeutic interventions.

3 METHODOLOGY

I will first introduce my research questions and hypotheses. Next, I will describe the devices used in the studies, followed by a detailed overview of the software developed for the research. I will outline the setup for each study and conclude by presenting the key questionnaires used throughout the research.

Research Questions and Hypothesis

For my research, I set four groups of research questions and hypotheses, where each has a subject of interest:

1RQ and 1H: The first group deals with the comparisons of mobile phones, tablets, monitors, and VR headsets to find the best visualization device.

2RQ and 2H: These latter questions address the outcomes of VR use in the Corsi-Test: how Virtual Reality can be better used to allow flexibility and adaptability in test protocols, taking into consideration its possible adverse effects, such as increased heart rate and stress levels.

3RQ and 3H: The third category investigates the impacts of VR in rehabilitation, especially cognitive, neurological, and therapy-based applications. This section represents the investigation of how VR could improve user engagement along with therapeutic outcomes, considering

whether VR tends to show more promise in certain therapeutic areas rather than others.

4RQ and 4H: The fourth group examines the use of 3D virtual environments in rehabilitation, including the impacts of different atmospheres—ranging from happy to darker settings—on stress, anxiety, and overall rehabilitation outcomes. The guided breathing techniques within these environments are compared for effectiveness in terms of reducing stress levels.

Devices

A variety of devices were used throughout the research, with two playing a main role. The first was the Oculus Quest 2, a Virtual Reality headset used extensively for conducting VR-based testing. Its advanced capabilities allowed participants to engage in immersive environments, making it ideal for the study's Virtual Reality component. The second device is the Polar H10 chest strap, which recorded the heart rate of the participants in experiments. The Polar H10 is highly accurate and precise, and it was employed in this study for pulse data collection. These two devices were the base of the technological setup within the framework of the research conducted.

Main studies

Comparing Visualization Devices for Rehabilitation

This study compared four devices (mobile phone, tablet, monitor, VR headset) using a cycling video to observe the physiological impact on 33 participants (mean age 27) while monitoring their heart rates. The goal was to assess differences in engagement linked to different display types. In collaboration with psychologists from Eötvös Loránd University, the research has since been expanded. A new study involving 44 participants—each completing both the traditional and VR-based Corsi memory tasks—has been conducted, with the results currently under publication.

Virtual Reality Implementation of the Corsi-Test

The Corsi-Test was adapted into a VR format and tested on 14 participants (mean age 29). Results indicated that 60% of participants experienced reduced pulse rates when using the VR version compared to the traditional test, suggesting potential stress reduction benefits. In collaboration with psychologists from Eötvös Loránd University, the research has since been expanded. A new study involving 44 participants—each completing both the traditional and VR-based Corsi memory tasks—has been conducted, with the results currently under publication.

User Experience in Virtual Rehabilitation

This study analyzed user reviews of VR rehabilitation games, focusing on six categories: Physical Therapy, Cognitive Rehabilitation, Neurological Rehabilitation, Pediatric Rehabilitation, Psychological Rehabilitation, and Social Skills/Communication. The feedback helped evaluate user satisfaction and therapeutic effectiveness across various types of VR applications.

The Impact of 3D Environments

A pilot and main study tested the effect of breathing exercises in VR versus a traditional setting. The pilot involved 10 participants, split into VR and control groups. The main study expanded with 15 participants, assessing relaxation and engagement levels in three different VR environments.

Software

Several software was developed for the research. Notable highlights include:

Corsi-Test in Virtual Reality

This VR-based software automates the traditional Corsi-Test, removing the need for a test administrator by using flashing cubes to indicate sequences. Users observe the sequence and then use VR controllers to replicate it. The test's difficulty can be adjusted by changing the interval between flashes, useful for assessing cognitive

development, especially in children. VR tests include child-friendly environments, such as boys' and girls' bedrooms, enhancing engagement. Users navigate these 3D spaces, starting the test at a table with cubes.

Breathing Exercises Software

Developed using Unity, the software features three unique 3D forest environments to evoke different emotions. It includes guided breathing exercises, facilitated by a character, to teach: box breathing [35,36], 4-7-8 breathing [37], humming breath [38,39].

The integration of these elements aims to create an immersive and interactive experience for cognitive and relaxation exercises.

Phython script for Analysis

A Python script was developed to retrieve recent Steam reviews, saving the data as CSV files. The script included functions to fetch reviews by timestamp and save them, utilizing libraries such as requests, datetime, and csv. The reviews were analyzed using Python code that performed text preprocessing, feature extraction, and sentiment analysis. The process involved tokenizing, removing stopwords, lemmatizing, and applying Bag of Words (BoW) and TF-IDF methods [40-42]. Sentiment analysis tools like TextBlob and VADER were used to classify reviews as positive, neutral, or negative, offering insight into user satisfaction [43]. Word frequency analysis

excluded terms related to gaming to emphasize therapeutic and experiential aspects. Reviews were compared across categories to identify trends, strengths, and areas for improvement. Statistical analyses, including T-tests, assessed variations in word count and sentiment between categories, revealing significant differences in user feedback. Visualizations created with Matplotlib and Seaborn presented data trends effectively [45-47].

Questioners

In the studies, a combination of self-developed and well-known questionnaires was employed to gather comprehensive data. The State-Trait Anxiety Inventory (STAI) was utilized to assess anxiety on two levels: STAI-T measured general anxiety as a stable personality trait, while STAI-S evaluated participants' immediate or situational anxiety levels [48]. The Depression Anxiety Stress Scales (DASS-21), a 21-item tool, provided a detailed profile of symptoms related to depression, anxiety, and stress, offering insights into the participants' mental health status [49]. Additionally, the User Experience Questionnaire (UEQ) captured participants' perceptions of the VR environment's usability, efficiency, and enjoyment [50]. Finally, the System Usability Scale (SUS), questionnaire to measure of the VR system's overall usability [51].

4 KEY FINDINGS

In the research of comparing various displays, the VR head-mounted displays (HMDs) provided the most immersive and engaging experiences. Monitors served as a comfortable and practical alternative, offering high engagement levels but lower immersion compared to VR. Tablets and mobile phones ranked lowest in terms of immersion and engagement, highlighting the significant role that device size and the capacity for immersion play in shaping the user experience. The potential of VR in cognitive assessments was evident in studies featuring VR-based tools like the VR Corsi-Test, which demonstrated greater precision, flexibility, and adaptability than traditional assessment methods. Cognitive rehabilitation games in VR received positive feedback for their engaging and interactive qualities, contributing to improved therapeutic outcomes. However, neurological rehabilitation games faced challenges such as motion sickness and tracking errors, which hindered their effectiveness and user enjoyment. VR environments featuring positive stimuli, such as cheerful virtual settings, proved to be the most effective for reducing stress, as demonstrated by lower scores on the STAI-S.

5 THESIS SUMMARY

The dissertation findings can be organized into thesis groups, each representing a major area of investigation related to user experience with visualization devices, stress reduction, and rehabilitation outcomes through the use of virtual reality technology.

Thesis Group 1: User Experience with Visualization Devices

1T1: Based on participant ratings, I concluded that VR headsets provide the most immersive experience (68%), followed by monitors (64%), with tablets (26%) and phones (9%) rated significantly lower.

1T2: Drawing from motivational feedback, I found that VR headsets were rated most engaging (72%), with monitors next (68%), and tablets (52%) and phones (46%) less effective.

1T3: Analyzing user preferences, I determined that larger screens are favored, with 24-inch monitors (78%) and VR (69%) preferred over tablets (57%) and mobile phones (32%).

Main Conclusions for Thesis Group 1:

VR HMD displays are rated highest for immersion, attractiveness, and stimulation, making them the most

engaging devices. Monitors offer a strong alternative, perceived as less bothersome and more comfortable, which makes them ideal for longer and less intense sessions. Tablets and mobile phones fall behind in terms of user satisfaction, as they provide lower levels of immersion and engagement, making them less effective for activities that require strong user involvement. The participants showed a higher likelihood of using VR headsets and monitors at home for indoor activities. Across all therapeutic categories, larger displays were preferred over smaller devices, indicating that screen size influences the user experience and effectiveness in rehabilitation.

Thesis Group 2: General Impact of VR on Cognitive and Therapeutic Outcomes

2T1: Through comparative testing, I discovered that traditional methods in VR environments improve efficacy by 67%, reduce heart rate by 17%, and allow flexible, accurate digital adjustments.

Main Conclusions for Thesis Group 2:

The immersive nature of VR environments allows for more precise and flexible cognitive assessments, like the Corsi-Test, compared to traditional methods. Their adjustable settings enable tailored experiences that improve test outcomes and provide a calmer atmosphere, as evidenced by lower average heart rates. These

enhancements demonstrate VR's potential to revolutionize spatial memory assessments, yielding a 67% better user experience than conventional approaches.

Thesis Group 3: VR in Rehabilitation Applications

3T1: Based on user reviews, I conclude that Virtual Reality rehabilitation applications improve engagement and therapeutic outcomes, with an overall sentiment score of 0.75. Cognitive Rehabilitation Games received the highest satisfaction (0.129), significantly outperforming Neurological Rehabilitation Games (0.092, $p < 0.001$).

Main Conclusions for Thesis Group 3:

Cognitive rehabilitation games (CRG) received the highest user satisfaction, showing that VR stands in cognitive therapy by offering engaging and interactive experiences that enhance therapeutic outcomes. Neurological rehabilitation games (NRG), while promising, encounter technical issues, such as motion sickness and tracking errors, which reduce their effectiveness and user satisfaction. Physical rehabilitation games (PRG) received more mixed feedback, with users noting the need for customizable intensity levels, indicating that while VR has potential in physical therapy, it requires more personalization.

Thesis Group 4: Stress Reduction in VR Environments

4T1: After analyzing stress reduction through guided breathing exercises without visual or auditory stimuli, I found no significant difference in outcomes between immersive Virtual Reality environments and traditional physical settings, as measured by STAI-S questionnaires and heart rate data.

4T2: When visual and auditory elements were included in the VR setting, I found that the type of environment significantly influenced stress reduction during breathing exercises. A cheerful, sunny forest with natural sounds (positive-affective) led to greater stress reduction—8% more than the same forest in a neutral baseline condition and 15% more than the same forest presented as a dark, stormy, barren scene (negative-affective).

Main Conclusions for Thesis Group 4:

Happy virtual environments, such as sunny forests with natural sounds, significantly reduce stress levels more than neutral or dark stormy environments, proving the VR's ability to enhance psychological well-being. do. VR is effective for stress relief, especially when designed with a positive and engaging atmosphere, making it a promising tool for psychological interventions and relaxation therapies.

6 FUTURE RESEARCH DIRECTIONS AND IMPLICATIONS

The findings from this study provide a basis for future research in the area of VR and visualization devices for rehabilitation. Several areas of further investigation have emerged. Based on the long-term use of VR headsets and other visualization devices, I discuss how user engagement, comfort, and physical reactions might be affected during long-term rehabilitation sessions. This study investigated the optimal design of virtual environments in VR treatment, focusing on how different emotional stimuli, such as positive and neutral environments, could be applied to optimize stress alleviation and ensure treatment efficacy. Solve technical issues affecting some therapeutic categories, especially in the neurological rehabilitation game category, to ensure that VR tools are effective and accessible to all patients. There are also some areas, such as technical challenges in neurological rehabilitation games, that need to be sorted out before the full potential of VR can be achieved. Emphasizing a user-centered approach while persistently improving the technology is how virtual reality will ever be in a position to revolutionize both cognitive and physical rehabilitation, improve general treatment outcomes, and improving the quality of life.

7 SUMMARY OF THE OWN PUBLICATION

Below is a list of my publications grouped by year in the research topic. During this period, I have made 10 Hungarian conference presentations, 7 International conference presentations, and 2 Journal publications with Impact Factors. Additionally, I have 6 other Journal publications under review. In this list, "P" stands for presentations, "J" for journal publications, and "V" for episode from an online video series in Youtube.

2022

[P1] Szabó, P., Sikné Lányi, C., Schalbert, J., Kretz, Z., & Cserjési, R. (2022). „Légzés félelem nélkül" – Virtuális valóság alapú légzés javító játék tervezése post és long-Covid szindrómában szenvedő betegek rehabilitációjára [Conference presentation]. XXXV. Neumann Colloquium Conference, Szeged, Hungary. In: *Az egészségügyi informatika COVID előtt és COVID után - A XXXV. Neumann Kollokvium konferencia kiadványa*. pp 124-129.

[P2] Szabó, P., & Sikné Lányi, C. (2022). Android alapú alkalmazás tervezése 1-es típusú cukorbeteg gyermekek tanítására [Conference presentation]. XXXV. Neumann Colloquium Conference, Szeged, Hungary. In: *Az*

egészségügyi informatika COVID előtt és COVID után - A XXXV. Neumann Kollokvium konferencia kiadványa. pp 130-135.

2023

[V1] Szabó, P. (2023, Apr 12). How can we use VR to fight post-COVID syndrome? [Ep. 2]. Research Goes Live. YouTube. https://www.youtube.com/watch?v=_j427Z0SIMc

[J1] Szabó, P., Ara, J., Halmosi, B., Sik-Lanyi, C., & Guzsvinecz, T. (2023). Technologies designed to assist individuals with cognitive impairments. *Sustainability, 15(18), 13490.* https://doi.org/10.3390/su151813490, Impact Factor: 3.9

[P3] Szabó, P. (2023). Virtual Reality based serious games for older adults [Conference presentation]. *6th International Conference on Aging & Technology Fair (eng)aging!,* Prague, Czech Republic.

[P4] Sik-Lanyi, C., & **Szabó, P**. (2023). Developing an Android-based game for children with blindness or low vision [Conference presentation]. Association for the Advancement of Assistive Technology in Europe, Paris, France. In: *Book of Abstracts, 17th International Conference of the Association for the Advancement of Assistive Technology in Europe, AAATE 2023*. pp 231-233.

[P5] Szabó, P., & Sik-Lanyi, C. (2023). A digitális és hagyományos oktatás, generációs különbségek [Conference presentation]. XXIX. Multimedia in Education Conference, Szeged, Hungary. In: *29th Multimedia in Education Conference Proceedings - XXIX. Multimédia az oktatásban nemzetközi konferencia kiadvány*. pp 50-53.

[P6] Sikné Lányi, C., Guzsvinecz, T., Tálas, M., Halmosi, B., **Szabó, P.,** & Haneklaus, N. (2023). Játékra fel! – Virtuális Valóság alapú „Negotiation Game" [Conference presentation]. XXIX. Multimedia in Education Conference, Szeged, Hungary. In: *29th Multimedia in Education Conference: Conference Proceedings*. pp 70-75.

[P7] Szabó, P., Sik-Lanyi, C., Filotás, P., & Cserjési, R. (2023). Virtual reality-based game for rehabilitation: Corsi-test [Conference presentation]. 2nd IEEE International Conference on Cognitive Aspects of Virtual Reality, Veszprém, Hungary. In: *2nd IEEE International Conference on Cognitive Aspects of Virtual Reality – cVR 2023*. pp 29-32.

[P8] Szabó, P., Baranyi, P., & Sik-Lanyi, C. (2023). DOS-Windows-Virtual desktop [Conference presentation]. 2nd IEEE International Conference on Cognitive Aspects of Virtual Reality, Veszprém, Hungary. In: *2nd IEEE International Conference on Cognitive Aspects of Virtual Reality – cVR 2023*. pp 33-36.

[P9] Zsebi, S., **Szabó, P.,** Filotás, P., Sik-Lányi, C., & Cserjési, R. (2023). Enhancing neuropsychological assessment through virtual reality: A pilot study of the Corsi block tapping task [Conference presentation]. 2nd IEEE International Conference on Cognitive Aspects of Virtual Reality, Veszprém, Hungary. In: *2nd IEEE International Conference on Cognitive Aspects of Virtual Reality – cVR 2023*. pp 115-118

[P10] Szabó, P., & Sik-Lanyi, C. (2023). Virtual reality based serious games for memory skill improvement [Conference presentation]. XXXVI. Neumann Colloquium Conference, Veszprém, Hungary. In: *Orvosi informatika. A XXXVI. Neumann Kollokvium konferencia-kiadványa* pp 66-72.

[P11] Szabó, P. (2023). Revolutionizing rehabilitation through VR-based serious games. In: *Technicity Doctoral Workshop Conference - MOME* [Conference presentation].

2024

[J2] Szabó, P., Filotás, P., Sik-Lanyi, C., Zsebi, S., & Cserjési, R. (2024). Virtual reality implementation of the Corsi test and pilot study on acceptance. *Software Impacts, 21, 100693*. https://doi.org/10.1016/j.simpa.2024.100693, Impact Factor: 2.1

[P12] Szabó, P., & Sik-Lanyi, C. (2024, June 26-28). Immersive VR games for cognitive enhancement. In *womENcourage™ 2024: Responsible Computing for Gender Equality. ACM Celebration of Women in Computing*, Madrid, Spain.

[P13] Szabó, P., & Sik-Lanyi, C. (2024, July 8-12). User-friendly serious game design for diabetic preschool children. In: *International Conference on Computers Helping People with Special Needs (ICCHP 24)*, JKU Linz, Austria. pp 65-69.

[P14] Szabó, P., & Sik-Lanyi, C. (2024, Sept. 3-6). Design virtual reality games that instruct proper breathing techniques with dynamically changing virtual environment. In: *15th International Conference on Disability, Virtual Reality & Associated Technologies.,* Prague, Czech Republic. pp 1-2.

[P15] Sik-Lanyi, C. & **Szabó, P.,** (2024, Sept. 3-6). Modelling realistic avatars for the "P-game" negotiation game. In: *15th International Conference on Disability, Virtual Reality & Associated Technologies*., Prague, Czech Republic. pp 1-3.

[P16] Szabó, P. (2024). Immersive VR games for cognitive enhancement. In XXVII. Tavaszi Szél Konferencia 2024 [Poster presentation]. In: *XXVII. Tavaszi Szél Konferencia 2024 – Absztraktkötet.* p. 683.

[P17] Soma, Z., Zsebi, P., Filotás, P., **Szabó, P**., Sik-Lányi, C., & Cserjési, R. (2024). Assessing the cognitive performance of different age groups using Virtual Reality technology and psychophysiology. In *15th Dubrovnik Conference on Cognitive Science: Memory, Space, Language* (p. 38, Paper: PS1-17). Central European Cognitive Science Association (CECOG).

MTMT profil:
https://m2.mtmt.hu/gui2/?type=authors&mode=browse&sel=10085867

IN REVIEW

I currently have 6 additional journal publications in review, and I will present at the AAATE 2025 conference in September, where I have two accepted full papers in the volume "Technology for Inclusion and Participation for All: Recent Achievements and Future Directions - 8th International Conference, AAATE 2025, Nicosia, Cyprus, September 10-12, 2025, Proceedings", which will be published by Springer.

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