MetaRehab: Enhancing Parkinson's Disease Rehabilitation through Gamified Virtual Reality, a Usability Study

MetaRehab: Enhancing Parkinson's Disease Rehabilitation through Gamified Virtual Reality, a Usability Study

Fabrizio Sulpizio, Leonardo Giannantoni, Francesco Strada, Andrea Bottino
Politecnico di Torino, Control and Computer Engineering Department
Torino, 10129, Italy. Email(s): {name.surname}@polito.it

***Abstract*—Motor impairment and cognitive decline are the most relevant symptoms of Parkinson's disease (PD), a neurodegenerative syndrome that is usually treated with pharmacological and rehabilitation therapy. However, traditional physical and cognitive rehabilitation approaches require frequent visits to specialized centers and often lack engagement, leading to demotivation and non-compliance. The increasing prevalence of neurodegenerative syndromes highlights the need for innovative, more sustainable and entertaining rehabilitation strategies. This study explores the potential of immersive Virtual Reality (VR) in physical and cognitive at-home rehabilitation. By incorporating gamification elements, our approach aims to increase patient motivation and engagement, which are crucial for successful rehabilitation outcomes. The use of Natural User Interfaces in the application increases user engagement and the user experience by enabling intuitive interactions and thus promoting a sense of agency. In addition, the VR environment utilizes different communication channels to deliver instructions and feedback on activities, ensuring that the system is accessible to individuals with different needs and preferences. In this paper, we describe the experimental evaluation of the usability and perceived effort of MetaRehab, the proposed VR-based rehabilitation process, prior to its application in a therapeutic context. These preliminary results provide a solid foundation for future enhancements aimed at adding new features and further increasing system inclusivity and engagement.**

***Index Terms*—motor and cognitive rehabilitation; neurological diseases; virtual reality; exergames; user experience.**

I. Introduction

Neurodegenerative diseases progressively impair neurological functions due to neuron damage and loss, leading to movement disorders and cognitive decline. Once damaged, neurons can no longer regenerate, which exacerbates the decline in motor and mental abilities. A prominent example of these syndromes is Parkinson's disease (PD), which manifests itself through uncontrollable movements, stiffness, and impaired balance and coordination. Symptoms worsen over time, affecting walking, speech, cognitive abilities, and mental health [1].

Although there is currently no cure for this category of diseases, physical exercise has been identified as an effective ally of drug treatments in rehabilitation therapy for PD, providing significant benefits in alleviating motor and cognitive symptoms [2]. In this context, traditional devices like treadmills and stationary bikes play a crucial role. In particular, treadmill training not only improves cognitive abilities and gait performance in patients with PD, but also influences brain connectivity patterns, suggesting promising approaches for the management of PD [3]. Similarly, intensive exercise on cycle ergometers has been shown to improve gait speed and endurance in PD patients [4]. However, despite the proven efficacy of exercise, regular patients' participation remains low [2]. Additional barriers to exercise adherence include social isolation, fatigue, poor access to exercise facilities, and financial constraints [5]. Despite the benefits, the repetitive nature of treadmill and cycling exercises can lead to boredom, gradually decreasing patient engagement in therapy. This risks reducing the effectiveness of rehabilitation efforts and may cause some patients to abandon their programs altogether [6].

Innovative solutions using gaming technologies and motion tracking sensors offer a promising alternative to address the problem of monotony in traditional rehabilitation routines [7]. Research with different patient groups – including patients recovering from strokes [8] and people with multiple sclerosis [9] – highlights the effectiveness of gaming technology in rehabilitation. The use of commercial gaming consoles offers promising results in terms of patient engagement and treatment adherence in home-based rehabilitation [10]. In addition, recent studies have shown how these interactive and immersive tools can be particularly effective in the treatment of chronic and degenerative conditions, providing innovative ways to improve patient outcomes and quality of life in conditions such as PD [11].

However, while these games represent a significant advancement in incorporating technology into PD rehabilitation, they often lack sufficient complexity and customization. Effective PD rehabilitation typically necessitates exercises that are specifically tailored to address the disease's distinct motor and non-motor symptoms, such as tremors, rigidity, and balance issues [12]. Furthermore, research shows that exercise programs focusing on goal-based motor skill learning, especially when combined with cognitive engagement, effectively benefit PD patients [13]. Known as dual-task training, this approach consists of two tasks – one cognitive, one physical – with distinct goals, practiced simultaneously [14].

This situation highlights the urgent need for a more comprehensive, patient-centered approach to therapy. Such an approach should not only fulfill the requirements of physical and cognitive rehabilitation but also significantly improve the user experience of current technology-based approaches. In this way, it would promote consistent patient engagement and thus improve the therapy's long-term adherence and overall effectiveness.

Building on these findings, this study presents MetaRehab, an immersive Virtual Reality (VR) application designed for the home rehabilitation of PD patients. MetaRehab integrates (virtual) domestic environments into its exercise protocol, mapping the latter to a pizza-baking task, exploiting a gamified narrative and rewarding mechanism. These settings aim to closely link the rehabilitation experience to the patient's everyday life and improve the relevance and utility of the proposed exercises [15]. MetaRehab focuses on the fine-grained use of the hand, creating natural user interfaces and providing multimodal feedback to create an engaging, interactive therapeutic environment. Unlike existing solutions, MetaRehab focuses on usability and user experience (UX) while implementing a strongly gamified protocol composed of several daily-life exercises for hand dexterity. Building on the latest VR technology, this research aims to transform PD rehabilitation into an enjoyable experience and improve accessibility and therapy adherence by allowing patients to perform therapy in the comfort of their own home, analyzing its usability and perceived physical and cognitive effort.

II. State of the Art

Several therapeutic solutions exist to restore brain functionalities in individuals affected by PD. Notably, dual-task training, consisting of a combination of physical and cognitive rehabilitation, yields substantive outcomes in restoring physical and cognitive capacities among patients [13]. Despite their efficacy, conventional rehabilitation methods often necessitate patient supervision in clinical settings, which can be logistically challenging and stressful for patients [5].

The advent of home-based and telerehabilitation platforms has been particularly noteworthy, especially given the constraints imposed on traditional therapy sessions by the COVID-19 pandemic. While platforms like the Wii have been praised for their potential in engagement and flexibility, usability issues for individuals with moderate impairments have also been highlighted, pointing towards the necessity for more user-friendly solutions [9], [10]. Innovative software like HomeCoRe stimulates cognitive abilities in PD patients with mild impairment through a series of adaptive sessions of 2D exercises planned remotely and analyzed by a therapist [16]. However, HomeCoRe's focus on cognitive tasks does not address the motor rehabilitation needs of PD patients. In contrast, the TELEP@RK study focuses on repetitive movements to improve motor symptoms like bradykinesia and hypokinesia in PD patients. While highly accepted by physiotherapists and patients, the lack of evolution of the used tool has been identified as a potential drawback that could affect long-term engagement [17]. Moreover, the repetitive nature of the proposed exercises may lead to diminished user interest over time, affecting long-term engagement. The same issue is highlighted in Gamboa et al. [18], presenting PlayTherapy, an interactive and movement-based mini-games platform. However, PlayTherapy's reliance on screen-based interactions limits its ability to immerse users fully or provide detailed feedback, impacting its engagement.

Fully immersive VR exergames with dual-task components present a paradigm shift in rehabilitation for PD patients [19]. The use of VR in rehabilitation has made significant progress, with real-time feedback and customizable experiences playing a crucial role [20]. These features have the potential to increase patient engagement and improve rehabilitation outcomes, as evidenced by findings from recent studies [21]. The expansion of VR in home-based rehabilitation, driven by technological advancements, affordability, and security, allows patients to participate in exercises at their convenience and in the comfort of their own space, alleviating the constant presence of medical professionals in rehabilitation settings, allowing the latter to allocate their time to more exigent situations [21]. Despite these positive outcomes, the potential of VR for PD rehabilitation has not yet been fully realized [20].

In Feng et al. [22], VR rehabilitation is investigated and compared to conventional physical therapy. The results showed that VR rehabilitation led to more significant improvements than conventional methods, indicating its effectiveness for PD patients. However, due to its different scope, this study does not explore a gamified narrative and a wider variety of exercises, thus offering a limited rehabilitation experience.

The effects of visual feedback cues on the walking abilities of patients with PD are explored in Badarny et al. [23]. While those exercising without visual feedback showed a negligible improvement, 56% of the subjects receiving VR visual feedback cues significantly improved walking speed and stride length, 68% of them maintained this improvement after a short break and 36% still showed significant progress a week later, suggesting VR visual feedback's potential in PD therapy programs. While this study showcases the benefits of VR visual feedback for PD patients, the user experience remains basic, confined to navigating a virtual checkerboard floor. This approach may limit engagement in the rehabilitation experience, lacking gamified environments and interactive scenarios that can enhance motivation and reduce monotony in therapy sessions.

Gamification has proven to be a clinically appropriate [24] and rehabilitation-boosting tool, distracting users from the repetitiveness of movement exercises by framing them as steps toward achieving in-game objectives, obtaining immediate rewards, or earning badges. Evidence of gamification efficacy in the rehabilitation of neurodegenerative disorders, including PD, is ubiquitous [25].

MetaRehab addresses the shortcomings of current PD rehabilitation by using gamification and offering various exercises in a VR environment to increase patient engagement, with a focus on improving fine hand movements. Specifically, it provides an immersive experience that resembles a home environment and a dynamic approach that aims to maintain patient interest and motivation.

III. METHODS

As previously mentioned, MetaRehab incorporates a gamified approach that utilizes the motivational elements of game design to encourage regular participation and adherence to rehabilitation treatments. The immersive VR environment, which is experienced via a VR headset, is designed to promote deep engagement and a sense of presence in a virtual space modeled after a home environment. This environment not only enhances relatability but also optimizes transfer and retention of rehabilitation outcomes by situating therapy in a context that is familiar to the patient and where movement disorders can significantly impact their life.

MetaRehab levels are based on precise upper body movement sequences that have been identified by medical experts as effective for the areas most affected by PD. This targeted approach ensures that the exercises are not only relevant but also highly effective in addressing the unique challenges faced by PD patients. In addition, the application encourages independent management of symptoms by providing the user with visual guidance on the required movements and reducing reliance on constant medical monitoring through automatic pose and movement recognition.

By leveraging the hand-tracking features of the VR headset, there is no need for any additional sensors to determine the hand's orientation in space, granting complete freedom in upper limb and hand dexterity rehabilitation. The application provides a natural interaction system that enables intuitive, hand-based interactions within the VR environment. This feature is particularly beneficial for VR novices and ensures ease of use and a more natural experience.

The rehabilitation journey within MetaRehab is designed like a pizza-baking process, with each level proposing a task that correlates with a step in pizza preparation. This narrative approach not only engages users in meaningful activities, but also provides clear, external cues that can effectively aid PD patients' movement [23]. To meet the diverse needs of users, including the deaf, instructions are provided through a combination of video, voice and text presented by a virtual assistant on a tablet that serves as a diegetic interface in the VR space.

Since the target users may not be familiar with VR technology, MetaRehab includes an initial tutorial to help them familiarize with the application. This tutorial covers the basic interactions, such as grasping and pronation/supination movements, laying the foundation for the subsequent levels.

A. MetaRehab: levels structure

The sequence and structure of the six levels designed for the rehabilitation program supported by MetaRehab are outlined in Fig. 1. Each level has been designed to progressively increase in complexity to challenge both the physical and cognitive skills essential for the treatment of neurodegenerative syndromes. In the first four levels, objects are automatically snapped and aligned to the user's hand. This mechanism ensures that the position and orientation of the objects match the user's hands, facilitating the interaction and the development of basic movement skills in the first levels. Snapping and alignment are disabled in the final two levels, increasing motor coordination and cognitive challenges and ensuring a comprehensive rehabilitation experience. Throughout the rehabilitation program, a virtual assistant plays a pivotal role in guiding and motivating the user through multi-channel instructions, encouragement and feedback. Successful movements are acknowledged with visual and auditory cues such as a tick icon and a gradually filling progress bar to increase the user's motivation [26]. After completing a level, participants receive immediate feedback via a pop-up window that displays their score (computed as a function of successful movements), the time taken to complete the task and a badge that rewards the user. This badge consists of pizza slices that are added each time a level ends, giving the user a tangible sense of achievement as they progress through the levels.

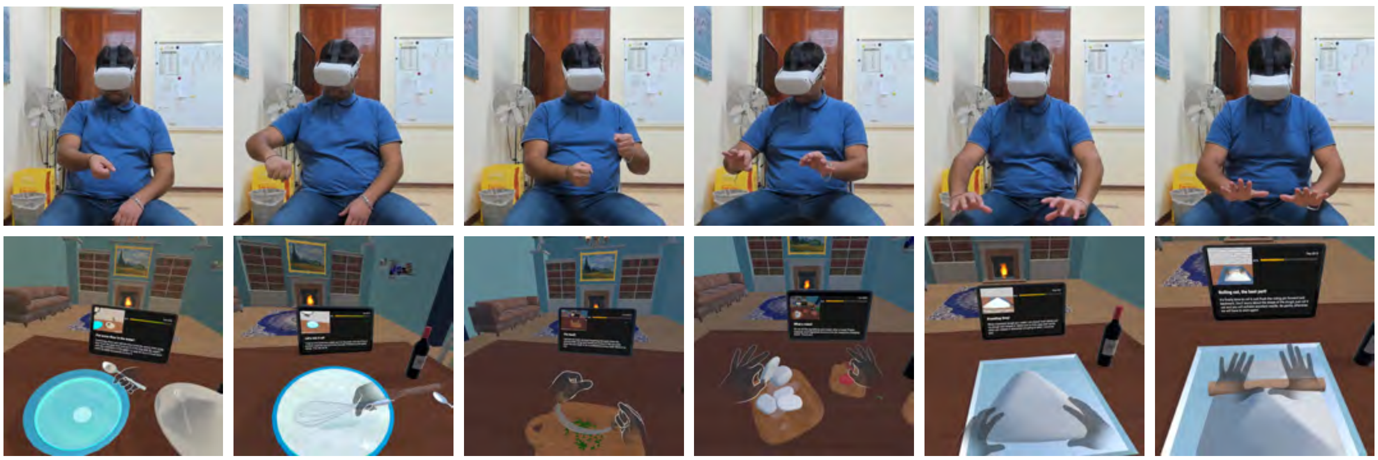
Level One - Basic hand movements. This first level (Fig. 1a) introduces basic hand movements such as pronation-supination of the hand and radial-ulnar deviation of the wrist, which are essential for everyday tasks such as pouring and turning objects. This level focuses on basic motor skills and forms the foundation for the more complex movements required in the following levels. The proposed task involves using a spoon to pour flour from a plate into a water container. An animated, transparent spoon shows the correct sequence of movements the user must perform.

Level Two - Advanced hand and shoulder coordination. This level (Fig. 1b) combines pronation-supination with shoulder movements. The user must mix the ingredients with a whisk, which requires hand and shoulder coordination. As in the first level, a transparent whisk guides the user's movements.

Level Three - Double hand coordination and elbow movement. This level (Fig. 1c) represents a significant increase in complexity. The user's task requires chopping basil with a mincing knife. Flexion and extension of the elbow joints are encouraged by emphasizing the movements of both hands alternately. As there are fewer visual aids than in the previous levels, users have to rely more on their intuition and understanding of the movements, which increases their autonomy and self-efficacy.

Level Four - Pinch movements and cognitive challenges. Here (Fig. 1d), the focus shifts to fine motor skills involving the opposition of the thumb and index finger (i.e., pinching movements) combined with a cognitive challenge. The user must organize a cluttered table of ingredients, which requires observation and logical thinking. This level combines physical control with mental processing and provides dual-task training beneficial for neurodegenerative diseases [13].

Level Five - Complex movements with reduced support. This level (Fig. 1e) trains more complex movements of the hand, wrist, and elbow, as well as abduction of the thumb. The users have to knead pizza dough, which requires coordinated, complex movements without the help of automatic snapping. The dough is deformed according to the user's interaction,



(a) Level 1. Basic hand movements.
(b) Level 2. Advanced hand and shoulder coordination.
(c) Level 3. Double hand coordination and elbow movement.
(d) Level 4. Pinch movements and cognitive challenges.
(e) Level 5. Complex movements with reduced support.
(f) Level 6. Wrist flexion-extension and force sensitivity.

Fig. 1: Out-of-game view (top) and in-game view (bottom) of the game levels described in Section III-A.

conveying a stronger sense of presence and agency and adding a creative element that increases fun and motivation while demanding greater precision and coordination.

Level Six - Wrist flexion-extension and force sensitivity. The final level (Fig. 1f) focuses on wrist flexion and extension and introduces physics-like force sensitivity. The user controls a rolling pin to roll the pizza dough into a flat shape. The rolling pin responds to varying degrees of (virtually) applied force, enriching the experience with an additional dynamic that requires nuanced movement control and physical effort.

Final scene. The rehabilitation process is concluded with a non-interactive scene in which the virtual assistant encourages users to exercise frequently. This scene serves as a motivational and reflective moment that reinforces the gamified narrative and recognizes users' success.

B. Implementation

The MetaRehab application was developed in Unity for the Meta Quest 2 device. However, it can also be deployed on any other VR headset with hand-tracking capabilities thanks to the portability features of the Unity environment. The Meta Quest 2 was chosen because it is a cost-effective device that offers a high-resolution visual experience and processing power appropriate for this application.

IV. Results

This section presents the evaluation of the MetaRehab system, focusing on its usability, the effort perceived by the users and their experience when interacting with the application. To evaluate these three aspects, we respectively used the System Usability Scale (SUS) [27], the NASA Task Load Index (NASA-TLX) [28] and a custom questionnaire designed to understand users' VR perception and identify any issues with upper limb mobility (Table III). Additional questions were about demographic data and subjects' prior experience with VR applications.

A. Experimental protocol

The participants were asked to use the MetaRehab application until they completed all levels or experienced sickness. After that, they had to fill out the proposed questionnaires.

Our participant pool consisted of 28 individuals aged 22 to 68 years, with 50% of them between 22 and 24 years old. All participants were free of neurological disorders. This initial testing phase helps identify and mitigate potential safety issues like cybersickness, allowing for design improvements based on user feedback. Moreover, it adheres to ethical standards by ensuring the app is safe and effective before being introduced to a potentially more vulnerable patient population. As for the users, 92.9% had no problems with hand mobility, and 56.3% had never tried VR.

B. Discussion

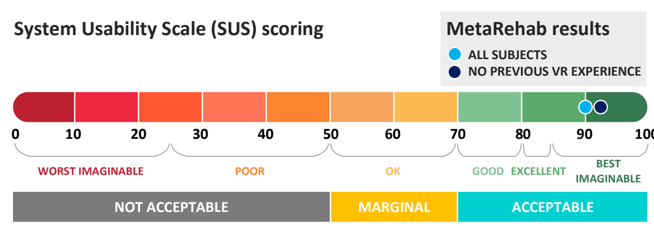


Fig. 2: System Usability Scale (SUS) [29] and MetaRehab average scoring: 90% (cyan dot) on all participants, 92.5% (blue dot) on participants with no previous VR experience.

The results of the SUS questionnaire (Table I) show an average score of 90 out of 100, corresponding to excellent usability (Fig. 2). It is particularly noteworthy that this value rose to 92.5 for participants with no previous VR experience, which indicates the intuitive design of the system. Over 90% of participants stated that the UI was user-friendly finding it easy to use (SUS3) and 64.3% felt that they could use the system

SUS						
Statement		1	2	3	4	5
SUS1	I think that I would like to use this system frequently.	0%	0%	0%	42.8%	57.2%
SUS2	I found the system unnecessarily complex.	64.4%	28.5%	7.1%	0%	0%
SUS3	I thought the system was easy to use.	0%	7.1%	0%	57.2%	35.7%
SUS4	I think that I would need the support of a technical person to be able to use this system.	64.4%	21.4%	7.1%	7.1%	0%
SUS5	I found the various functions in this system were well integrated.	0%	0%	7.1%	35.7%	57.2%
SUS6	I thought there was too much inconsistency in this system.	92.9%	7.1%	0%	0%	0%
SUS7	I would imagine that most people would learn to use this system very quickly.	0%	0%	21.4%	21.4%	57.2%
SUS8	I found the system very cumbersome to use.	64.3%	28.6%	7.1%	0%	0%
SUS9	I felt very confident using the system.	0%	7.1%	7.1%	42.9%	42.9%
SUS10	I needed to learn a lot of things before I could get going with this system.	71.4%	14.3%	14.3%	0%	0%
Average SUS score		90 out of 100				

TABLE I: SUS results. Levels of agreement from very low (1) to very high (5).

NASA-TLX						
Question		1-4	5-8	9-12	13-16	17-20
TLX1	How mentally challenging was the task?	57.2%	28.6%	7.1%	7.1%	0%
TLX2	How physically demanding was the task?	49.9%	43.0%	7.1%	0%	0%
TLX3	How successful were you in accomplishing the goals of the task?	0%	0%	7.1%	21.4%	71.5%
TLX4	How time-pressured was the task?	57.2%	21.4%	21.4%	0%	0%
TLX5	How hard did you have to work to accomplish your level of performance?	57.2%	21.4%	7.1%	14.3%	0%
TLX6	How irritated, stressed, or annoyed were you during the task?	64.3%	14.3%	7.1%	14.3%	0%

TABLE II: NASA-TLX results: from 1 (really low) to 20 (really high).

without technical assistance (SUS4), which is a crucial aspect for rehabilitation at home.

The NASA-TLX results (Table II) indicate that most participants did not perceive the task as mentally or physically demanding (TLX1), which may contradict our objective of providing physical and cognitive stimulation. Nevertheless, this suggests that the movements were intuitive. Notably, older participants ($\geq$ 65 years) reported heightened levels of mental engagement, scoring it 10 out of 20, with the global average consisting of 4 out of 20. However, the sample size within this age bracket was insufficient for definitive conclusions. Subsequent investigations will seek to confirm this observation with a more extensive cohort of older participants.

Additional questions			
Question		Yes	No
A1	Do you have upper limbs mobility related issues?	7.1%	92.9%
A2	Have you ever tried Virtual Reality?	35.7%	56.3%
A3	Did you experience cybersickness?	14.3%	85.7%
A4	Do you think that rehabilitation using Virtual Reality can be more engaging than without it?	100%	0%

TABLE III: Additional questions results

Regarding task accomplishment, a significant 71.5% of users reported feeling very successful in completing the entire app. Only 7.1% of respondents gave themselves a neutral performance rating of 9-12 out of 20 (TLX3). Stress or irritation was only reported by 14% of participants (TLX6). The post-experience questionnaire (Table III) revealed a unanimous preference for VR's gamified rehabilitation over the theoretical scenario of undertaking identical exercises without VR integration (A4). Only 4 users out of 28 experienced cybersickness (A3), with no in-game reports severe enough to necessitate halting their experience. After concluding the experience the totality of the sample that reported cybersickness stated that they experienced slight headaches. These results indicate no significant issues and a potential for broad acceptance of VR-based therapeutic interventions.

C. Limitations

While this study provides valuable insight into the development and potential of the MetaRehab application, it also has some limitations that should be acknowledged and addressed in future research.

A significant limitation is the lack of testing with the intended target, specifically individuals with Parkinson's or other neurodegenerative conditions. Consequently, the findings might not fully capture the app's usability, accessibility, and effectiveness for this group. Their particular challenges, such as motor and cognitive impairments, may significantly affect their interaction with and benefit from the application. Future studies should include testing with the target group to verify the suitability and effectiveness of the application for their specific needs.

Another critical limitation is the lack of data on the actual effectiveness of the rehabilitation intervention. While the application shows promise in engaging users and delivering a user-friendly experience, there is no empirical evidence that it effectively improves motor or cognitive function in patients with neurodegenerative diseases, nor that the gamified VR approach effectively improves retention. Therefore, clinical trials and longitudinal studies with actual patients are needed to assess long-term use, user retention, and sustained effectiveness of the rehabilitation process over time.

V. Conclusions

This project highlights the potential of VR in neurological rehabilitation by integrating inclusivity and gamification, offering a compelling self-rehabilitation treatment for individuals with neurological disorders. Participant feedback highlights the effectiveness of VR in cognitive and physical stimulation, and in maintaining user interest. Key to these results is the user-friendly design of the system, which was well received, as shown by the results of the SUS questionnaire. Most importantly, the minimal reports of cybersickness and the positive experiences of users suggest that this VR approach can be seamlessly integrated into everyday routines and offers a suitable method of enhancing traditional rehabilitation.

Future work includes not only testing with the target population to improve usability and effectiveness, but also expanding our investigation to evaluate clinical outcomes. We also plan to refine game dynamics, improve inclusivity through features such as preferred hand selection, voice commands and multilingual support, and customize content to match and adapt to individual disease progression. Additional gamification aspects, such as personal and community leaderboards, will be explored to further engage users.

ACKNOWLEDGMENT

The authors would like to thank SynArea Consultants S.r.l. for promoting the study.

REFERENCES

[1] B. R. Bloem, M. S. Okun, and C. Klein, "Parkinson's disease," *The Lancet*, vol. 397, no. 10291, pp. 2284–2303, 2021.

[2] T. Ellis and L. Rochester, "Mobilizing parkinson's disease: the future of exercise," *Journal of Parkinson's disease*, vol. 8, no. s1, pp. S95–S100, 2018.

[3] H. Ding, A. Droby, A. R. Anwar, M. Bange, J. M. Hausdorff, B. Nasseroleslami, A. Mirelman, I. Maidan, S. Groppa, and M. Muthuraman, "Treadmill training in parkinson's disease is underpinned by the interregional connectivity in cortical-subcortical network," *npj Parkinson's Disease*, vol. 8, no. 1, p. 153, 2022.

[4] I. Arcolin, F. Pisano, C. Delconte, M. Godi, M. Schieppati, A. Mezzani, D. Picco, M. Grasso, and A. Nardone, "Intensive cycle ergometer training improves gait speed and endurance in patients with parkinson's disease: a comparison with treadmill training," *Restorative neurology and neuroscience*, vol. 34, no. 1, pp. 125–138, 2016.

[5] S. Schootemeijer, N. M. Van Der Kolk, T. Ellis, A. Mirelman, A. Nieuwboer, F. Nieuwhof, M. A. Schwarzschild, N. M. De Vries, and B. R. Bloem, "Barriers and motivators to engage in exercise for persons with parkinson's disease," *Journal of Parkinson's disease*, vol. 10, no. 4, pp. 1293–1299, 2020.

[6] K. Jack, S. M. McLean, J. K. Moffett, and E. Gardiner, "Barriers to treatment adherence in physiotherapy outpatient clinics: a systematic review," *Manual therapy*, vol. 15, no. 3, pp. 220–228, 2010.

[7] K. Thomson, A. Pollock, C. Bugge, and M. Brady, "Commercial gaming devices for stroke upper limb rehabilitation: a systematic review," *International Journal of Stroke*, vol. 9, no. 4, pp. 479–488, 2014.

[8] D. M. Peters, A. K. McPherson, B. Fletcher, B. A. McClenaghan, and S. L. Fritz, "Counting repetitions: an observational study of video game play in people with chronic poststroke hemiparesis," *Journal of Neurologic Physical Therapy*, vol. 37, no. 3, pp. 105–111, 2013.

[9] M. Plow and M. Finlayson, "A qualitative study exploring the usability of nintendo wii fit among persons with multiple sclerosis," *Occupational therapy international*, vol. 21, no. 1, pp. 21–32, 2014.

[10] J. Wingham, K. Adie, D. Turner, C. Schofield, and C. Pritchard, "Participant and caregiver experience of the nintendo wii sportstm after stroke: qualitative study of the trial of wiitm in stroke (twist)," *Clinical rehabilitation*, vol. 29, no. 3, pp. 295–305, 2015.

[11] J. C. Möller, D. Zutter, and R. Riener, "Technology-based neurorehabilitation in parkinsons disease - a narrative review," *Clinical and Translational Neuroscience*, vol. 5, no. 3, 2021.

[12] K. J. Bower, J. Louie, Y. Landesrocha, P. Seedy, A. Gorelik, and J. Bernhardt, "Clinical feasibility of interactive motion-controlled games for stroke rehabilitation," *Journal of neuroengineering and rehabilitation*, vol. 12, no. 1, pp. 1–12, 2015.

[13] H. Johansson, A.-K. Folkerts, I. Hammarström, E. Kalbe, and B. Leavy, "Effects of motor–cognitive training on dual-task performance in people with parkinson's disease: a systematic review and meta-analysis," *Journal of Neurology*, vol. 270, no. 6, pp. 2890–2907, 2023.

[14] Y. Xiao, T. Yang, and H. Shang, "The impact of motor-cognitive dual-task training on physical and cognitive functions in parkinson's disease," *Brain Sciences*, vol. 13, no. 3, p. 437, 2023.

[15] C. G. Goetz, B. C. Tilley, S. R. Shaftman, G. T. Stebbins, S. Fahn, P. Martinez-Martin, W. Poewe, C. Sampaio, M. B. Stern, R. Dodel *et al.*, "Movement disorder society-sponsored revision of the unified parkinson's disease rating scale (mds-updrs): scale presentation and clinimetric testing results," *Movement disorders: official journal of the Movement Disorder Society*, vol. 23, no. 15, pp. 2129–2170, 2008.

[16] S. Bernini, F. Stasolla, S. Panzarasa, S. Quaglini, E. Sinforiani, G. Sandrini, T. Vecchi, C. Tassorelli, and S. Bottiroli, "Cognitive telerehabilitation for older adults with neurodegenerative diseases in the covid-19 era: a perspective study," *Frontiers in Neurology*, vol. 11, p. 623933, 2021.

[17] M. Blanc, A.-L. Roy, B. Fraudet, P. Piette, E. Le Toullec, B. Nicolas, P. Gallien, E. Leblong *et al.*, "Evaluation of a digitally guided self-rehabilitation device coupled with telerehabilitation monitoring in patients with parkinson disease (telep@ rk): open, prospective observational study," *JMIR Serious Games*, vol. 10, no. 1, p. e24946, 2022.

[18] E. Gamboa, C. Ruiz, and M. Trujillo, "Improving patient motivation towards physical rehabilitation treatments with playtherapy exergame." in *pHealth*, 2018, pp. 140–147.

[19] S. J. Yun, S. E. Hyun, B.-M. Oh, and H. G. Seo, "Fully immersive virtual reality exergames with dual-task components for patients with parkinson's disease: a feasibility study," *Journal of NeuroEngineering and Rehabilitation*, vol. 20, no. 1, p. 92, 2023.

[20] C. G. Canning, N. E. Allen, E. Nackaerts, S. S. Paul, A. Nieuwboer, and M. Gilat, "Virtual reality in research and rehabilitation of gait and balance in parkinson disease," *Nature Reviews Neurology*, vol. 16, no. 8, pp. 409–425, 2020.

[21] S.-H. Kwon, J. K. Park, and Y. H. Koh, "A systematic review and meta-analysis on the effect of virtual reality-based rehabilitation for people with parkinson's disease," *Journal of neuroengineering and rehabilitation*, vol. 20, no. 1, p. 94, 2023.

[22] H. Feng, C. Li, J. Liu, L. Wang, J. Ma, G. Li, L. Gan, X. Shang, and Z. Wu, "Virtual reality rehabilitation versus conventional physical therapy for improving balance and gait in parkinson's disease patients: a randomized controlled trial," *Medical science monitor: international medical journal of experimental and clinical research*, vol. 25, p. 4186, 2019.

[23] S. Badarny, J. Aharon-Peretz, Z. Susel, G. Habib, and Y. Baram, "Virtual reality feedback cues for improvement of gait in patients with parkinson's disease," *Tremor and Other Hyperkinetic Movements*, vol. 4, 2014.

[24] L. Gavish, O. Weissberger, and Y. Barzilay, "Gamification of cervical spine physiotherapy by virtual reality software: Is this real rehabilitation?" *Games for Health Journal*, 2023.

[25] S. Adlakha, D. Chhabra, and P. Shukla, "Effectiveness of gamification for the rehabilitation of neurodegenerative disorders," *Chaos, Solitons & Fractals*, vol. 140, p. 110192, 2020.

[26] B. A. Neibling, S. M. Jackson, K. S. Hayward, and R. N. Barker, "Perseverance with technology-facilitated home-based upper limb practice after stroke: a systematic mixed studies review," *Journal of neuroengineering and rehabilitation*, vol. 18, pp. 1–26, 2021.

[27] J. Brooke, "Sus: A quick and dirty usability scale," *Usability Eval. Ind.*, vol. 189, 11 1995.

[28] S. G. Hart and L. E. Staveland, "Development of nasa-tlx (task load index): Results of empirical and theoretical research," in *Advances in psychology*. Elsevier, 1988, vol. 52, pp. 139–183.

[29] J. Brooke, "Sus: a retrospective," *Journal of Usability Studies archive*, vol. 8, pp. 29–40, 2013.