# Virtual Reality in the Rehabilitation

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Over the past two decades, virtual reality technology (VRT)-based rehabilitation has been increasingly examined and applied to assist patient recovery in the physical and cognitive domains. The advantages of the use of VRT in the neurorehabilitation field consist of the possibility of training an impaired function as a way to stimulate neuron reorganization (to maximize motor learning and neuroplasticity) and restoring and regaining functions and abilities by interacting with a safe and nonthreatening yet realistic virtual reality environment (VRE). Furthermore, VREs can be tailored to patient needs and provide personalized feedback on performance. VREs may also support cognitive training and increases patient motivation and enjoyment. Despite these potential advantages, there are inconclusive data about the usefulness of VRT in neurorehabilitation settings, and some issues on feasibility and safety remain to be ascertained for some neurological populations.

Keywords: virtual reality technology (VRT)-based rehabilitation ; virtual reality (VR) ; rehabilitation ; brain injury ; neurophysiology

## 1. Introduction

There is no unique definition of virtual reality (VR). The concept's depictions include "the use of interactive simulations to provide users with opportunities to engage in environments that appear and feel similar to real-world objects and events" [1], "an advanced form of a human-computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion" [2], "a range of computing technologies that present artificially generated sensory information in a form that people perceive as similar to real-world objects or events" [3], or "the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real-world objects and events" [4].

Regardless of its definition, VR consists of a simulated experience of a natural or imagery environment that may or may not resemble a life-like experience. VR-based technology (VRT) consists of implementing VR using multimedia devices to allow individuals to interact with a VR environment (VRE). VR devices are essentially made of a multimedia display that provides sensory information to the user (including visual, auditory, and haptic information) and a control device that collects the user's actions (including motions, gestures, and speech). For instance, a VRT device can include motion-sensing gloves for life-like hand control (a form of VRT input) and a desktop display for showing the VRE generated by the software and the VRE interaction feedback (a VRT output, including auditory and video feedback, as well as sensory and force feedback through haptic technology).

VR needs to be distinguished from extended reality (XR), which includes augmented reality (an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities) and mixed reality (the merging of real and virtual worlds to produce new environments and visualizations, where physical and digital objects co-exist and interact in real-time). Another type of VR consists of text-based networked VR, i.e., cyberspace (that allows integrating different VR components, including sensors, signals, connections, transmissions, processors, and controllers to generate an interactive VRE that is accessible remotely).

VRT is classified according to the degree of immersion in the VRE generated by the VR device itself, including the non-immersive (traditional computer screen or tablet), semi-immersive (large 3D screen), and fully-immersive VREs (360° screens or head-mounted displays—HMDs) [5]. The degree of immersion depends on the level of isolation from the physical world that the VRE offers to the user [4]. A fully immersive VR can be achieved "by combining computers, HMDs, body tracking sensors, specialized interface devices, and real-time graphics to immerse a participant in a computer-generated simulated world that changes in a natural way with head and body motion" [6][7][8][9][10]. In this regard, first-person VREs using HMDs provide the participant with 3D depth perception and change the simulated view as the real-world head moves. Besides, a first-person VRE can be achieved using specially designed rooms with multiple large screens (e.g., the computer-assisted rehabilitation environment, CAREN; Motek Medical BV, Netherlands). Conversely, non-immersive or semi-immersive VR (using computers and console game systems) involves the simultaneous perception of both natural and virtual worlds [11][12]. The degree of immersion is thus a technology-related issue [1], and this critically affects the sense of embodiment, i.e., the "psychological perception of being in or existing in the VE in which one is immersed" [13][14]. Instead, this is a psychological, perceptual, and cognitive consequence of immersion, but it influences the motor-related processes [5].

A successful neurorehabilitation program needs to be intensive, repetitive, assist-as-needed, and task-oriented. VRT has been increasingly used in the neurorehabilitation field to help patients train an impaired physical and cognitive function in order to stimulate neuron reorganization (i.e., to maximize motor learning and neuroplasticity) [15][16][17] and restore and regain some functions and abilities. VR enables integrating physical activity into a motor task (including a game) that requires active core and body movements to control the VR experience, which aids rehabilitation training featuring intensive and repetitive issues. Indeed, a VRE allows an individual to interact with a safe and nonthreatening yet realistic environment [4], allowing moderate intensity exercises and a high degree of repetition [18]. Furthermore, VREs can be tailored to patient needs and provide personalized feedback on performance [4]. Also, VR can support cognitive training and increase a patient's motivation and enjoyment, thus potentiating rehabilitation training thanks to the fact that most exercises are task-oriented. In this regard, exercise-based games or "exergames" have become an interesting approach to support conventional rehabilitation [19]. Lastly, it is necessary to consider that VR has somewhat lower costs when compared with other advanced rehabilitation therapies (e.g., robot-assisted therapies), where it can be used independently by the patient and it is adaptable for at-home use if a telerehabilitation service is available, like that with a virtual reality rehabilitation system (VRRS; Khymeia, Italy) [20][21].

Despite these potential advantages, there are inconclusive data on the usefulness of VR in neurorehabilitation settings [18][22][23][24][25][26]. VR seems useful only as an adjunct to standard clinical treatment rather than as a single intervention [23][24][25]. Furthermore, the usefulness of VR has also been reported as limited [23][25][26]. Finally, some issues regarding feasibility and safety remain in some neurological populations [24][25][26]. The present brief overview aims to summarize the available literature on VR applications in neurorehabilitation settings [19][27][28], including Parkinson's disease (PD) [24][29], multiple sclerosis (MS) [30], strokes [18][31], and cognitive decline [32] while discussing the pros and cons of VR and introducing the practical issues for research.

## 2. Development and Findings

### 2.1. Potential Advantages and Side Effects of VR Rehabilitation

Overall, the available data in the literature do not fully support the effectiveness of VR exercise when compared to traditional training methods. There are inconclusive data regarding the usefulness of VR in neurorehabilitation settings, mainly owing to methodological discrepancies (with particular regard to sample size, randomization, blinding, control groups, trial duration, compared devices, and outcome measures), especially concerning cognitive rehabilitation [18][23][24][25][26][27]. VR seems valuable and practical only as an adjunct to standard clinical treatment rather than as a single intervention [18][23][24][25][26][27]. Furthermore, some reports have rated the usefulness of VRT as limited [18][23][24][25][26][27]. Finally, some issues regarding feasibility and safety remain for the neurological population [18][23][24][25][26][27].

It seems reasonable to forecast that immersive VRT will add several benefits in addition to conventional rehabilitation training [18][23][24][25][26][27]. There is evidence that these approaches may provide patients with more interesting, motivating, and persistent motor practice and permit patients to be trained in activities that may be dangerous if practiced in a real-world setting (e.g., driving). Indeed, performing a task that may be now too difficult, time-consuming, or impossible to do in a natural world setting is instead feasible when using VR. Furthermore, VRT enables therapists to provide standardized rehabilitation protocols, controlled stimulus presentations, and objective clinical progress and performance measures. VREs can be tailored to patient needs and provide personalized feedback on performance [4]. Lastly, it is necessary to consider that many VR devices have somewhat lower costs than other advanced rehabilitation therapies (e.g., robot-assisted therapies), can be used independently by the patient, and are adaptable for at-home use if a telerehabilitation service is available [21][22].

Notwithstanding these potential advantages, there are some possible side effects of VR that must be kept into account. First, simulator sickness is a kind of motion sickness experienced by people in motion or vehicle simulations. This syndrome is characterized by discomfort, fatigue, nausea, and disorientation. It arises from the discrepancy between a more vigorous motion perceived by vision and hearing and a weaker motion perceived by the vestibular system and proprioception, which leads to simulator sickness. The frequency and severity of simulator sickness depend on the device

(HMD vs. non-wearable displays), the type of tasks (e.g., walking vs. driving), and the individual's clinical and demographical features. In this regard, some fear new devices or are very sensitive to simulated environments. This may even induce persecutory delusion and paranoia in schizophrenia patients.

Conversely, reducing anxiety symptoms has been reported following fully immersive VR treatment (e.g., using CAREN) [33][34]. Furthermore, VR practice may cause lasting motion sickness, so it is necessary to take care of the patients during and after treatment. Besides, VR may induce eyestrain-related issues such as eye fatigue and discomfort, dryness and redness, and reduced visual acuity, which falls under computer vision syndrome [34][35]. These findings are more frequent when using HMDs, but this significantly depends on the given display characteristics [33][34]. All these factors need to be considered carefully when considering VRT-based rehabilitation [33][34].

### 2.2. Issues for Research

There are still some new or partially explored issues in VRT implementation in the neurorehabilitation field. Importantly, we have to consider the opportunity to adopt HMDs vs. standard displays. The former allows generating better immersion and life-like experiences due to the 3D depth perception achieved via binocular discrepancy and a dynamic field of view with the use of head tracking systems; however, such VR devices can be particularly expensive (e.g., HMDs and 360° VRT devices), non-available in every rehabilitation centre, sometimes challenging to wear and deal with, and can yield significant ocular disturbances.

The neurophysiological basis for the use of VRT to foster motor and cognitive function recovery still requires elucidation. Indeed, it has been proposed that VR yields a reshaping of frontoparietal connectivity in the alpha and theta frequency range. This may be extended to all the neuropsychiatric and neurocognitive disorders that share a connectivity breakdown within frontoparietal networks.

There is a particular population who may benefit from VRT to alleviate both patient and physiotherapist burden, including patients in an intensive care unit, those in a minimally conscious state, and those suffering from a severe traumatic brain injury. The positive effects of VRE may also be found regarding cognitive impairment in patients with muscle diseases, which is an unexplored issue. All these populations are very frail and feature severely limited functional communication capacities. Although preliminary, the data shown in the literature suggest that VRT may help increase communication and facilitate the delivery of a rehabilitation service.

Another population that likely requires high care for physical, psychological, and cognitive rehabilitation is the post-COVID-19 population. Owing to the unfortunately growing number of cases and consequent healthcare system burden, VRT may facilitate the delivery of fast and tailor-made rehabilitation at a distance [35].

Lastly, definite cost–benefit analysis is still missing, and although the cost of VR devices has dropped significantly, the software and hardware management required is still highly demanding, with particular regard to customized VREs. Therefore, tailored rehabilitation planning is always mandatory to better manage individuals and optimize resource allocation.

## 3. Conclusions

The available studies on VRT for rehabilitation purposes from the past two decades are primarily preliminary and feature small sample sizes. Furthermore, the studies dealing with VRT as an assessment method are more numerous than those harnessing VRT as a training method; however, the reviewed studies show the great potential of VRT in rehabilitation. The comprehensive application of VRT is foreseeable shortly due to the increasing availability of low-cost VR devices and the possibility of personalizing VR settings and delivering VR at home, thus actively contributing to reducing healthcare costs and improving rehabilitation outcomes through tailored rehabilitation at a distance.

### References


1. Weiss, P.L.; Kizony, R.; Feintuch, U.; Katz, N. Virtual reality in neurorehabilitation. In Textbook of Neural Repair and Re habilitation; Selzer, M., Clarke, S., Cohen, L., Duncan, P., Gage, F., Eds.; Cambridge University Press: Cambridge, UK, 2006; pp. 182–197.
2. Schultheis, M.T.; Rizzo, A.A. The Application of Virtual Reality Technology in Rehabilitation. Rehabil. Psychol. 2001, 46, 296–311.
3. Wilson, P.N.; Foreman, N.; Stanton, D. Virtual reality, disability and rehabilitation. Disabil. Rehabilit. 1997, 19, 213–220.

4. Henderson, A.; Korner-Bitensky, N.; Levin, M. Virtual Reality in Stroke Rehabilitation: A Systematic Review of Its Effectiveness for Upper Limb Motor Recovery. Top. Stroke Rehabil. 2007, 14, 52–61.
5. Juliano, J.M.; Spicer, R.P.; Vourvopoulos, A.; Lefebvre, S.; Jann, K.; Ard, T.; Liew, S.-L. Embodiment is related to better performance on a brain–computer interface in immersive virtual reality: A pilot study. Sensors 2020, 20, 1204.
6. Wingham, J.; Adie, K.; Turner, D.; Schofield, C.; Pritchard, C. Participant and caregiver experience of the Nintendo Wii Sports TM after stroke: Qualitative study of the trial of WiiTM in stroke (TWIST). Clin. Rehabil. 2015, 29, 295–305.
7. Piron, L.; Turolla, A.; Tonin, P.; Piccione, F.; Lain, L.; Dam, M. Satisfaction with care in post-stroke patients undergoing a telerehabilitation programme at home. J. Telemed. Telecare 2008, 14, 257–260.
8. Donoso Brown, E.V.; Dudgeon, B.J.; Gutman, K.; Moritz, C.T.; McCoy, S.W. Understanding upper extremity home programs and the use of gaming technology for persons after stroke. Disabil. Health J. 2015, 8, 507–513.
9. Plow, M.; Finlayson, M. A qualitative study exploring the usability of Nintendo Wii fit among persons with multiple sclerosis. Occup. Ther. Int. 2014, 21, 21–32.
10. Miller, K.J.; Adair, B.S.; Pearce, A.J.; Said, C.M.; Ozanne, E.; Morris, M.M. Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: A systematic review. Age Ageing 2014, 43, 188–195.
11. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred reporting items for systematic re-views and meta-analyses: The PRISMA Statement. PLoS Med. 2009, 6, e1000097.
12. Higgins, J.P.T.; Altman, D.G.; Gotzsche, P.C. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011, 343, 5928.
13. Heeter, C. Being There: The Subjective Experience of Presence. Presence Teleoperators Virtual Environ. 1992, 1, 262–271.
14. Draper, J.V.; Kaber, D.B.; Usher, J.M. Telepresence. Hum. Factors 1998, 40, 354–375.
15. Riva, G. Virtual environments in clinical psychology. Psychotherapy 2003, 40, 68–76.
16. Mat Rosly, M.; Mat Rosly, H.; Davis, O.A.M.G.M.; Husain, R.; Hasnan, N. Exergaming for individuals with neurological disability: A systematic review. Disabil. Rehabil. 2017, 39, 727–735.
17. Levin, M.F.; Weiss, P.L.; Keshner, E.A. Emergence of virtual reality as a tool for upper limb rehabilitation: Incorporation of motor control and motor learning principles. Phys. Ther. 2015, 95, 415–425.
18. Laver, K.E.; Lange, B.; George, S.; Deutsch, J.E.; Saposnik, G.; Crotty, M. Virtual reality for stroke rehabilitation. Cochrane Database Syst. Rev. 2017, CD008349.
19. Bonnechère, B.; Jansen, B.; Omelina, L.; Van Sint Jan, S. The use of commercial video games in rehabilitation: A systematic review. Int. J. Rehabil. Res. 2016, 39, 277–290.
20. Prosperini, L.; Fortuna, D.; Giannì, C.; Leonardi, L.; Marchetti, M.R.; Pozzilli, C. Home-based balance training using the Wii balance board: A randomized, crossover pilot study in multiple sclerosis. Neurorehabilit. Neural Repair 2013, 27, 516–525.
21. Sparks, D.A.; Coughlin, L.M.; Chase, D.M. Did too much Wii cause your patient's injury? J. Fam. Pract. 2011, 60, 404–409.
22. Pietrzak, E.; Cotea, C.; Pullman, S. Using commercial video games for upper limb stroke rehabilitation: Is this the way of the future? Top. Stroke Rehabil. 2014, 21, 152–162.
23. Saposnik, G.; Levin, M. For the Stroke Outcome Research Canada (SORCan) Working Group. Virtual reality in stroke rehabilitation: A meta-analysis and implications for clinicians. Stroke 2011, 42, 1380–1386.
24. Barry, G.; Galna, B.; Rochester, L. The role of exergaming in Parkinson's disease rehabilitation: A systematic re-view of the evidence. J. Neuroeng. Rehabil. 2014, 1, 33.
25. Cheok, G.; Tan, D.; Low, A.; Hewitt, J. Is Nintendo Wii an effective intervention for Individuals with stroke? A systematic review and meta-analysis. J. Am. Med. Dir. Assoc. 2015, 16, 923–932.
26. Dos Santos, L.R.A.; Carregosa, A.A.; Masruha, M.R.; Dos Santos, P.A.; Da Silveira Coêlho, M.L.; Ferraz, D.D.; Da Silva Ribeiro, N.M. The use of Nintendo Wii in The rehabilitation of post-stroke patients: A systematic review. J. Stroke Cereb. Dis. 2015, 24, 2298–2305.
27. Ravenek, K.E.; Wolfe, D.L.; Hitzig, S.L. A scoping review of video gaming in rehabilitation. Disabil. Rehabil. Assist. Technol. 2016, 6, 445–453.
28. Cano Porras, D.; Siemonsma, P.; Inzelberg, R.; Zeilig, G.; Plotnik, M. Advantages of virtual Reality in the rehabilitation of balance and gait: Systematic review. Neurology 2018, 22, 1017–1025.

29. Dockx, K.; Bekkers, E.M.; Bergh, V.V.D.; Ginis, P.; Rochester, L.; Hausdorff, J.M.; Mirelman, A.; Nieuwboer, A. Virtual reality for rehabilitation in Parkinson's disease. Cochrane Database Syst. Rev. 2016, 12, CD010760.
30. Massetti, T.; Trevizan, I.L.; Arab, C.; Favero, F.M.; Ribeiro-Papa, D.C.; de Mello Monteiro, C.B. Virtual reality in multiple sclerosis—A systematic review. Mult. Scler. Relat. Disord. 2016, 8, 107–112.
31. Viňas-Diz, S.; Sobrido-Prieto, M. Virtual reality for therapeutic purposes in stroke: A systematic review. Neurologia 2016, 31, 255–277.
32. Gates, N.J.; Rutjes, A.W.; Di Nisio, M.; Karim, S.; Chong, L.Y.; March, E.; Martínez, G.; Vernooij, R.W. Computerised cognitive training for 12 or more weeks for maintaining cognitive function in cognitively healthy people in late life. Cochrane Database Syst. Rev. 2020, 2, CD012277.
33. Rosenfield, M. Computer vision syndrome: A review of ocular causes and potential treatments. Ophthalmic Physiol. Opt. 2011, 31, 502–515.
34. Kesztyues, T.I.; Mehlitz, M.; Schilken, E.; Weniger, G.; Wolf, S.; Piccolo, U.; Irle, E.; Rienhoff, O. Preclinical Evaluation of a Virtual Reality Neuropsycho-logical Test System: Occurrence of Side Effects. Cyberpsychol. Behav. 2000, 3, 343–349.
35. Smits, M.; Staal, J.B.; van Goor, H. Could Virtual Reality play a role in the rehabilitation after COVID-19 infection? BMJ Open Sport Exerc. Med. 2020, 6, e000943.