Virtual Reality-Based Rehabilitation for Postural Control and Functional Outcome in Patients with Parkinson's Disease: A Narrative Review

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ABSTRACT

Purpose of Review: Virtual reality (VR)–based rehabilitation has gained attention as a potential therapeutic approach for neurological disorders. Recently, there has been growing interest in its use to improve postural control, balance, and functional mobility in patients with Parkinson's disease (PD). This review aims to examine and discuss the current evidence on the effectiveness of VR in enhancing postural control and functional outcome in individuals with PD. **Methods:** A comprehensive search of PubMed, Cochrane Library, PEDro, Science Direct and Google Scholar was conducted using keywords such as Parkinson's disease, virtual reality, postural control, balance, and neurorehabilitation. This review included articles published between 2012–2025, and only English-language studies were reviewed. Unpublished manuscripts, conference abstracts, and studies with insufficient scientific rigor were excluded. **Results:** Evidence from randomized controlled trials indicates that VR interventions can improve postural stability, functional mobility, and, in some cases, reduce fall risk in PD. VR also enhances cognitive-motor performance through dual-task training, while immersive, interactive, and gamified environments increase motivation, adherence, and long-term engagement. However, study sample sizes are generally small, and protocols vary widely, limiting the ability to establish standardized treatment guidelines. **Conclusion:** Current literature indicates that Virtual reality is an effective adjunct for improving postural control in Parkinson's disease, whereas its effect on functional outcome is less consistent. Future research should prioritize standardized protocols, larger trials, and long-term follow-up.

Keywords: Parkinson's disease, virtual reality, rehabilitation, postural control, balance, functional outcome, neurorehabilitation.

1. INTRODUCTION

Parkinson's disease (PD) is one of the most common neurodegenerative disorders, affecting more than 10 million individuals worldwide. It is characterized by progressive loss of dopaminergic neurons in the substantia nigra pars compacta, resulting in hallmark motor symptoms such as bradykinesia, rigidity, resting tremor, and postural instability [(1, 2)]. Alongside these motor impairments, PD presents with a wide range of non-motor symptoms including cognitive decline, depression, and sleep disturbances, all of which contribute to reduced independence and quality of life [(3)].

Among the motor symptoms, postural instability and gait disturbances are particularly disabling and are strongly associated with falls, injuries, and loss of autonomy [(4)]. Unlike tremor and rigidity, which often respond to dopaminergic medications, balance and gait impairments are less responsive to pharmacological treatment [(2)]. Surgical options such as deep brain stimulation provide some benefit but are not universally applicable, underscoring the importance of physiotherapy-based interventions [(5)].

Conventional rehabilitation approaches have shown measurable benefits; however, their long-term impact is often limited by poor adherence and reduced engagement once structured therapy ends. Moreover, these approaches may not sufficiently provide the multisensory, progressively challenging, and task-specific practice necessary for neuroplastic changes [(6)].

Virtual reality (VR) has emerged as a potential solution to these limitations by offering safe, interactive, and customizable environments for rehabilitation. VR enables patients to practice functional activities while receiving multisensory feedback that promotes motor learning and neuroplasticity. In PD rehabilitation, VR can replicate daily-life scenarios, such as navigating obstacles or maintaining balance during dual-tasking, which may directly translate into improved safety and functional performance [(7, 8)].

Recent randomized controlled trials have reported promising effects of VR-based rehabilitation in PD. Studies have demonstrated improvements in balance, postural stability, and mobility compared to conventional physiotherapy, though findings remain variable across outcomes [(9-12)].

This narrative review summarizes evidence on VR-based rehabilitation for postural control and functional outcomes in Parkinson's disease patients.

2. Overview of Postural Control

Postural control refers to the ability to maintain stability and orientation of the body during both static and

Received: 05/05/2025
Accepted: 07/07/2025

dynamic tasks. It ensures that the body's center of mass is maintained within the base of support, whether standing still, initiating movement, or responding to external perturbations Effective postural control is not a passive process but involves continuous adjustments driven by sensory feedback, motor responses, and cognitive integration. It is fundamental to safe mobility, functional independence, and fall prevention, making it a core focus of rehabilitation in neurological disorders such as Parkinson's disease (PD) [13].

The control of posture is achieved through the integration of multiple systems. The sensory systems (visual, vestibular, and somatosensory) provide input about body position and environmental conditions. The central nervous system interprets these signals, coordinating anticipatory and reactive responses, while the musculoskeletal system executes the motor outputs necessary to maintain balance Anticipatory postural adjustments prepare the body for voluntary movement, while reactive adjustments restore stability after unexpected perturbations. Cognitive processes also contribute, particularly when dual-tasking or adapting to complex environments [14].

In PD, basal ganglia dysfunction disrupts the automaticity of movement and scaling of motor responses, leading to profound deficits in postural control. Patients often demonstrate delayed or absent anticipatory postural adjustments, reduced limits of stability, and difficulty recovering from perturbations. This results in increased sway during quiet standing, difficulties with transitional movements such as sit-to-stand, and impaired responses to slips or trips. These deficits not only increase fall risk but also reduce confidence in mobility, contributing to activity restriction and further deconditioning [15].

Postural control impairments in PD are exacerbated under dual-task conditions, when motor and cognitive tasks must be performed simultaneously. Walking while talking, navigating obstacles while focusing on a secondary task, or responding to distractions in the environment often result in greater instability and increased fall risk. This phenomenon reflects the increased reliance of PD patients on attentional resources for postural control, as automaticity of movement is impaired. Rehabilitation strategies that integrate dual-task training are therefore essential to address real-world challenges faced by PD patients [2].

3.Conventional Approaches to Postural Control Training

Physiotherapy is central to managing postural instability in Parkinson's disease (PD). Evidence supports a variety of strategies, including Balance-oriented and core stabilization programs, strengthening and resistance training, gait training, and external cueing all of which have been shown to improve balance, mobility and reduce fall risk [16-18]. Group-based physiotherapy further enhances balance while providing psychosocial benefits such as motivation and social interaction [19]. Complementary approaches, including Tai Chi, yoga, and aquatic therapy, have also demonstrated positive effects on stability, mobility, and fall reduction [20, 21].

Despite these advances, conventional therapy often falls short of fully addressing the complex motor, sensory, and cognitive contributors to postural instability. Limitations remain in terms of long-term adherence, as benefits tend to decline after supervised programs, and in ecological validity, since many exercises fail to prepare patients for the unpredictable and dual-task demands of everyday mobility. These limitations underscore the need for approaches that not only improve balance in controlled settings but also translate effectively into daily life. This gap highlights the need for innovative adjunctive therapies such as Virtual reality (VR) [22].

4. Overview of Virtual Reality

Virtual reality (VR) is a computer-based technology that generates interactive environments designed to replicate or simulate real-world or imagined scenarios. It provides users with visual, auditory, and, in some systems, haptic feedback, creating a sense of immersion and presence within the virtual space. VR systems are generally classified into immersive systems, such as head-mounted displays (HMDs), provide a three-dimensional interactive environment that closely mimics real-life settings. Semi-immersive platforms, including projection-based systems like CAVE (Cave Automatic Virtual Environment), deliver partial immersion, while non-immersive VR employs screen-based or gaming-console platforms to deliver training tasks. The degree of immersion influences patient engagement, ecological validity, and therapeutic outcomes [23].

VR has gained increasing attention for its ability to create safe, controlled, and customizable environments where patients can practice functional activities. Unlike traditional therapy, it replicates real-life challenges such as obstacle negotiation, walking through crowded environments, or dual-task activities under safe conditions. This controlled exposure allows patients to progressively develop motor and cognitive skills while minimizing the risk of falls or injury, making VR particularly suited for neurological populations such as PD, who frequently demonstrate impaired adaptability and reduced ability to compensate for environmental demands [24].

The benefits of VR arise from several mechanisms. It facilitates motor learning through repetitive, goal directed practice with immediate feedback [13]. It promotes sensory integration by recalibrating visual, vestibular, and proprioceptive inputs [24]. It stimulates neuroplasticity by activating cortical and subcortical circuits involved in balance and motor control [5]. VR also enhances cognitive motor coupling through dual task training that replicate real world challenges [8]. Furthermore, gamification and interactive design increase motivation and adherence, supporting long term participation in therapy [6].

A major limitation of conventional physiotherapy is reduced adherence over time, as repetitive exercises can become monotonous and disengaging. VR addresses this issue by incorporating gamified elements, such as scoring systems, rewards, and interactive avatars, transforming therapy into an engaging and enjoyable experience [25].

Clinical studies consistently report that patients with PD describe VR training as more stimulating and motivating compared to standard exercises, leading to higher participation and adherence rates. This motivational aspect is especially critical in PD rehabilitation, which requires long-term commitment due to the progressive nature of the disease [26, 27].

5. Applications of VR in Neurological Rehabilitation and Parkinson's Rehabilitation

VR has been applied across a wide range of neurological conditions, including stroke, multiple sclerosis, cerebral palsy, and traumatic brain injury, where it has demonstrated improvements in motor recovery, functional mobility, and quality of life [23].

In PD, evidence from randomized controlled trials shows significant improvements in postural control, particularly on the Berg Balance Scale and Mini-BESTest [10, 11]. VR has also been shown to reduce gait variability, enhance limits of stability, and increase balance confidence [28].

Compared with conventional therapy, VR yields superior or equivalent outcomes in functional outcome measures such as the Timed Up and Go and Dynamic Gait Index [6, 29]. Semi-immersive treadmill-based VR systems (e.g., C-Mill) improve gait adaptability, while non-immersive telerehabilitation offers accessible alternatives for home-based care [11, 30].

Beyond motor outcomes, VR interventions have been associated with improved mood, cognitive function, and quality of life, suggesting holistic benefits [25]. High adherence and patient satisfaction further support feasibility [6].

6. Advantages and Limitations of VR

The advantages of VR are evident in its ability to provide safe yet challenging practice environments. Patients can attempt high risk tasks such as obstacle negotiation without danger of falling. The technology allows progressive difficulty, individualized feedback, and integration of multiple sensory modalities. Nevertheless, limitations remain. Variability in protocols, session length, and outcome measures reduces comparability across studies. Access to advanced VR systems may be limited by cost and infrastructure, and some patients may initially struggle with usability. Occasional side effects such as cybersickness or visual fatigue have been reported but are generally rare and self-limiting [29].

7. Clinical Implications of VR

VR-based rehabilitation offers a scalable, engaging, and accessible complement to traditional physiotherapy, enhancing patient motivation, adherence, and outcomes. Home-based VR systems support telerehabilitation for patients with mobility limitations or in remote areas. Interventions can be tailored to individual abilities, with adjustable task difficulty, real-time feedback, and gamification to promote motor learning and long-term engagement. VR also provides a safe environment for practicing high-risk movements, such as obstacle negotiation or dual-task walking. These findings support incorporating VR into standard PD rehabilitation, particularly for patients at moderate disease stages.

8. Limitations of This Review

Limitations should be acknowledged. First, the narrative review design is inherently subjective and may be prone to publication bias. Second, the absence of a quantitative synthesis prevents estimation of pooled effect sizes, limiting the strength of conclusions. Third, the included studies display wide variability in VR equipment, levels of immersion, training intensity, and outcome measures, which complicates comparisons and reduces generalizability.

9. CONCLUSION

VR represents a safe, feasible, and effective adjunct to conventional rehabilitation for PD. Evidence supports its role in enhancing postural control, with emerging but less consistent results for broader functional outcomes. Future research should prioritize standardization of protocols, multicenter trials with larger sample sizes, and long-term follow-up studies to establish the durability of VR's effects.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

Authors state no conflict of interest.

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