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RESEARCH ARTICLE

A Randomized Controlled Trial for Comparing the Efficacy of Virtual Reality and Proprioceptive Sensory Reweighting via Blindfolded Training on Postural Stability and Functional Mobility in Parkinson's Disease

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Abstract: Postural instability and gait disturbances are clinical challenges in the management of Parkinson's disease, frequently resulting in a loss of autonomy and an elevated incidence of falls. Conventional rehabilitation often fails to address the complex sensory deficits inherent in the disease. This research work evaluates the comparative impact of two distinct neurorehabilitation paradigms: Virtual Reality-based training, which utilizes enriched multisensory feedback, and Blindfolded Balance Training, which emphasizes proprioceptive and vestibular reliance through visual occlusion. 30 participants with idiopathic Parkinson's disease (Hoehn and Yahr stages II–III) were randomized to receive either virtual reality interventions or blindfolded exercises, both supplemented by conventional physiotherapy, over a four-week period. Assessments conducted via the Berg Balance Scale and the Timed Up and Go test reveal significant improvements in both cohorts post-intervention. Statistical analysis demonstrates that while both modalities are effective, virtual reality-based training provides superior gains in both static and dynamic balance parameters. The interactive and task-specific nature of the virtual environment appears to facilitate more robust motor learning and neurological adaptation compared to isolated sensory reweighting. These results indicate that incorporating technologically driven feedback mechanisms into physical therapy protocols enhances functional outcomes. While immersive technology offers more pronounced benefits, blindfolded training remains a viable, resource-efficient strategy for promoting sensory-motor integration. Utilization of these diverse sensory training methods could offer a more holistic approach to neurorehabilitation, targeting the multifaceted motor impairments characteristic of progressive parkinsonism.

Keywords: Parkinson's Disease; Neurorehabilitation; Virtual Reality; Proprioceptive Training; Postural Balance.

1. Introduction

Gait dysfunction and postural instability are cardinal features of Parkinson's disease (PD), stemming from the progressive degeneration of dopaminergic neurons within the substantia nigra pars compacta. This neurological decline disrupts the basal ganglia-thalamocortical circuitry, leading to the characteristic motor symptoms of bradykinesia, rigidity, and tremors [1]. As the disease advances, the automation of movement is compromised, forcing patients to rely more heavily on cortical attention and visual feedback to maintain equilibrium [2]. This reliance on visual cues is often a compensatory mechanism for impaired proprioception and vestibular processing, yet it leaves patients vulnerable in environments with low lighting or complex visual stimuli [3].

The deterioration of balance mechanisms in PD is a primary contributor to a high frequency of falls, which often result in debilitating injuries, fractures, and a subsequent fear of falling [4]. This fear creates a deleterious cycle of activity restriction, further muscle atrophy, and social isolation. Short, shuffling steps, known as festination, and the phenomenon of freezing of gait (FOG) significantly reduce walking efficiency and the ability to navigate obstacles or change directions safely [5]. For individuals at moderate disease stages, specifically Hoehn and Yahr II and III, these impairments directly correlate with a marked reduction in health-related quality of life and increased caregiver burden [6].

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Traditional physiotherapy remains a cornerstone of PD management, focusing on stretching, strengthening, and gait re-education. However, recent scientific inquiries have pivoted toward interventions that target the brain's neuroplastic potential through sensory-motor integration [7]. Virtual Reality (VR) has emerged as a potent tool in this domain, providing an immersive, safe environment where patients can engage in task-oriented exercises with real-time visual and auditory feedback [8]. VR aims to bypass traditional motor pathways and encourage the development of new neural connections by stimulating multiple sensory pathways [9].

Conversely, Blindfolded Balance Training (BBT) operates on the principle of sensory reweighting. The central nervous system is forced to recalibrate and increase the "gain" or sensitivity of the remaining proprioceptive and vestibular systems [10] by intentionally occluding visual input. This technique aims to decrease the pathological over-reliance on vision, potentially improving the patient's internal sense of body position and stability [11]. While VR seeks to enrich the sensory environment, BBT seeks to refine the body's internal feedback loops.

Despite the documented benefits of various exercise modalities, there remains a lack of direct comparative evidence regarding the efficacy of enriched feedback versus sensory deprivation in the context of PD rehabilitation. This randomized controlled trial seeks to fill this gap by comparing the effectiveness of VR-based training and BBT when integrated with standard physical therapy. The primary objective is to quantify improvements in functional balance using the Berg Balance Scale (BBS) and mobility through the Timed Up and Go (TUG) test. This study aims to provide clinicians with data-driven information to optimize rehabilitation protocols for patients suffering from sensory-motor deficits associated with parkinsonism.

2. Methodology

2.1. Study Design

A randomized controlled trial was conducted at the Department of Physiotherapy, Sri Ramakrishna Hospital, Coimbatore, spanning a period of six months. The study aimed to assess the comparative efficacy of two sensory-based interventions on postural control and mobility. Participants were recruited through the outpatient and inpatient neurology services of the hospital. Following an initial screening process, thirty individuals diagnosed with idiopathic Parkinson's disease were selected based on pre-defined eligibility criteria. Randomization was done using a simple random sampling technique, ensuring an equal distribution of fifteen participants into two parallel intervention groups: Group A (Virtual Reality Training) and Group B (Blindfolded Balance Training).

The research protocol was approved by the Institutional Ethics Committee of Sri Ramakrishna Hospital (Approval No.: COPT/MPT/ETHICS/06/2024). All procedures were performed in accordance with the Declaration of Helsinki. Prior to any data collection, participants were provided with a comprehensive explanation of the study objectives, procedures, and potential risks. Written informed consent was obtained from each participant, and they were informed of their right to withdraw from the trial at any stage without consequence to their standard medical care.

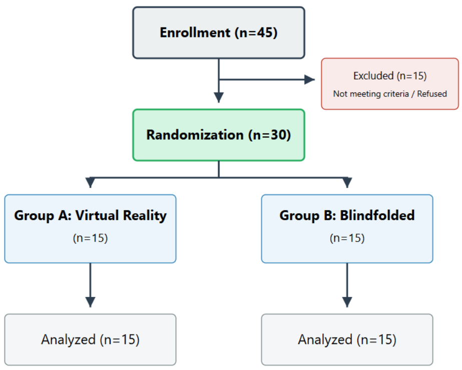

Figure 1. Study Design and Participant Recruitment

2.2. Eligibility Criteria

2.2.1. Inclusion Criteria

To ensure a homogenous sample with relevant functional deficits, participants were required to meet the following criteria: a definitive diagnosis of idiopathic Parkinson's disease; clinical staging between II and III on the Hoehn and Yahr scale, signifying mild to moderate bilateral involvement with some postural instability; age between 50 and 75 years; and a stable pharmacological regimen of anti-parkinsonian medication for at least four weeks prior to the study. Additionally, a Mini-Mental State Examination (MMSE) score of 24 or higher was mandatory to ensure cognitive capacity for following complex training instructions.

2.2.2. Exclusion Criteria

The study excluded individuals presenting with atypical or secondary forms of parkinsonism to avoid confounding variables. Further exclusion criteria included significant uncorrected sensory impairments (visual or auditory) that might impede the use of virtual reality systems or blindfolds; comorbid neurological conditions such as cerebrovascular accidents or peripheral neuropathy; and severe musculoskeletal pathologies like advanced osteoarthritis or recent fractures. Patients with unstable cardiovascular or respiratory conditions that would limit physical exertion, and those who had undergone deep brain stimulation surgery within the preceding six months, were also excluded.

2.3. Outcome Measures

Functional assessments were conducted at baseline and immediately following the four-week intervention period. Two primary tools were utilized to quantify changes in balance and mobility.

2.3.1. Berg Balance Scale (BBS)

The Berg Balance Scale is a 14-item clinical instrument designed to evaluate static and dynamic balance through various functional tasks, including sitting, standing, reaching, and turning. Each task is rated on a five-point ordinal scale (0 to 4), with a maximum cumulative score of 56. Higher scores reflect superior postural stability. This scale is highly regarded for its reliability and validity in assessing fall risk and balance changes in neurodegenerative populations [12].

2.3.2. Timed Up and Go (TUG) Test

Functional mobility was measured using the Timed Up and Go test, which records the time in seconds required for a participant to rise from a standard armchair, walk three meters at a comfortable pace, turn, return to the chair, and sit down. This test provides a reliable objective measure of dynamic balance and gait efficiency, where shorter completion times indicate enhanced mobility [13].

2.4. Intervention Protocols

Participants in both groups received treatment five days per week for four weeks, with each session lasting 45 minutes. Exercises were performed in sets of 20 repetitions, with structured rest periods provided to prevent fatigue.

2.4.1. Virtual Reality-Based Training (Group A)

Group A engaged in an interactive, task-oriented virtual reality program using a motion-tracking system that provided real-time visual feedback. The protocol focused on multi-directional weight shifting, obstacle navigation, and reaching tasks within a simulated environment. Activities included walking through virtual parks and avoiding stationary or moving targets. The system was calibrated to increase difficulty progressively as participants demonstrated improved control, thereby maintaining a consistent therapeutic challenge [14].

2.4.2. Blindfolded Balance Training (Group B)

Group B underwent a protocol focused on sensory reweighting by performing balance exercises while wearing a secure blindfold to eliminate visual input. Participants performed activities such as marching in place on various surfaces (firm floor and foam), treadmill walking at speeds ranging from 1 to 3 km/h, and directional stepping in response to verbal cues. These exercises aimed to heighten reliance on proprioceptive and vestibular feedback, encouraging internal stabilization strategies without the aid of visual orientation [15].

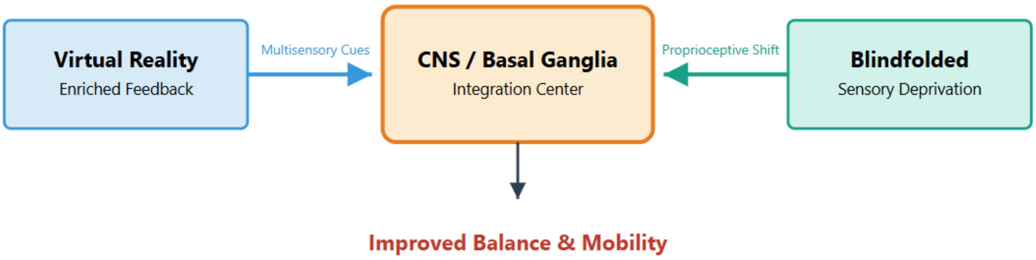

Figure 2. Differential pathways for Virtual Reality (external cueing) and Blindfolded training (internal reweighting).

Table 1. Interventions and Target Sensory Systems

Intervention Component	**Virtual Reality Training (Group A)**	**Blindfolded Balance Training (Group B)**
Primary Sensory Focus	Visual-Motor Integration & Enriched Feedback	Proprioceptive & Vestibular Reweighting
Visual Input	Real-time interactive digital feedback	Complete visual occlusion (Blindfold)
Core Activities	Obstacle navigation, Target reaching, Weight shifting	Marching on foam, Treadmill walking, Directional stepping
Feedback Mechanism	External (Visual/Auditory cues from VR)	Internal (Kinesthetic/Proprioceptive cues)
Common Element	Conventional PT (Stretching, Strengthening)	Conventional PT (Stretching, Strengthening)

2.4.3. Conventional Physiotherapy

Both cohorts received standard physiotherapy alongside their specific sensory training. This included stretching of major muscle groups, lower limb strengthening, basic gait re-education, and breathing exercises. This ensured that all participants received a baseline level of evidence-based care while allowing for the evaluation of the additional sensory-specific interventions.

2.5. Statistical Tests

Data were processed using statistical software, with the Shapiro–Wilk test applied to verify the normality of the distribution. For within-group comparisons of pre- and post-intervention scores, paired t-tests were employed. Independent t-tests were used to analyze the differences in improvement scores between Group A and Group B. A p-value of less than 0.05 was considered statistically significant for all tests.

3. Results

3.1. Participant Demographics

The demographic profile of the 30 participants indicated no significant differences between the two groups at baseline ($p > 0.05$). The mean age in Group A was 63.4 ± 6.1 years, compared to 62.7 ± 5.9 years in Group B. The disease duration was also comparable, with mean values of 6.2 ± 2.1 years and 6.5 ± 2.4 years, respectively. All participants maintained a high level of cognitive function as evidenced by MMSE scores (Group A: 26.8 ± 1.4; Group B: 27.1 ± 1.2). Initial scores on the BBS and TUG indicated a similar baseline level of functional impairment across both cohorts.

Table 2. Participant Demographics and Baseline Clinical Characteristics

Variable	**Group A (Virtual Reality, n=15)**	**Group B (Blindfolded, n=15)**	**p-value**
Age (Years, Mean ± SD)	63.4 ± 6.1	62.7 ± 5.9	0.72
Gender (Male / Female)	9 / 6	8 / 7	0.74
Disease Duration (Years, Mean ± SD)	6.2 ± 2.1	6.5 ± 2.4	0.63
Hoehn & Yahr Stage (II / III)	10 / 5	11 / 4	0.81
MMSE Score (Mean ± SD)	26.8 ± 1.4	27.1 ± 1.2	0.59
Baseline BBS Score (Mean ± SD)	38.80 ± 3.8	38.53 ± 4.1	0.66
Baseline TUG Time (Seconds, Mean ± SD)	16.47 ± 2.7	16.83 ± 2.9	0.78

3.2. Functional Improvements within-Group

Both intervention groups demonstrated statistically significant improvements across all outcome measures after the four-week training period. In Group A, the mean BBS score increased by 5.59 points ($t = 10.3952$, $p < 0.05$), while the TUG completion time was reduced by an average of 3.147 seconds ($t = 11.9596$, $p < 0.05$). Group B also showed significant gains, with the BBS score improving by 5.13 points ($t = 7.1669$, $p < 0.05$) and the TUG time decreasing by 2.067 seconds ($t = 7.5029$, $p < 0.05$). These results confirm that both enriched sensory feedback and sensory reweighting techniques contribute effectively to motor recovery.

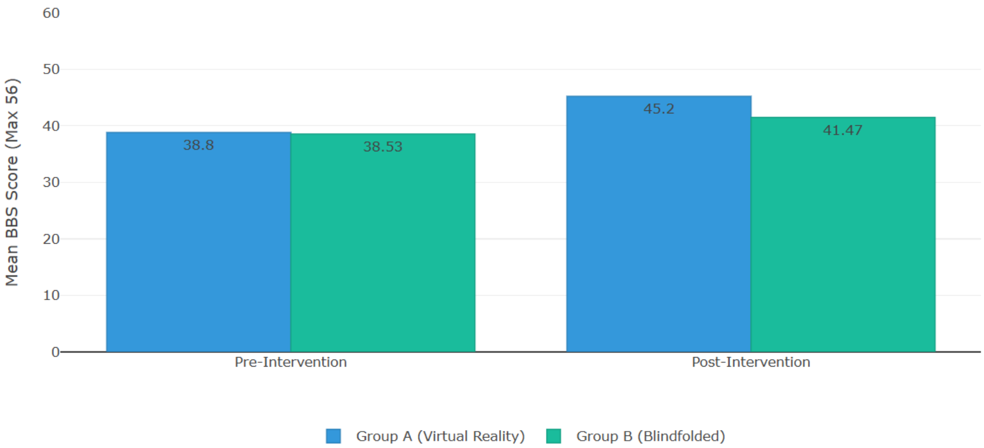

Figure 3. Improvement in Berg Balance Scale (BBS)

Table 3. Balance and Mobility Outcomes Within-Groups (Pre- vs. Post-Intervention)

Outcome Measure	Group	Pre-Intervention (Mean)	Post-Intervention (Mean)	Mean Difference	Calculated t-value	p-value
Berg Balance Scale	A (VR)	38.80	45.20	5.59	10.3952	< 0.05
	B (BBT)	38.53	41.47	5.13	7.1669	< 0.05
Timed Up and Go	A (VR)	16.473	13.327	3.147	11.9596	< 0.05
	B (BBT)	16.833	14.767	2.067	7.5029	< 0.05

3.3. Comparative Efficacy Between Groups

The between-group analysis revealed that the improvements observed in the Virtual Reality group were significantly greater than those in the Blindfolded Balance Training group. Post-intervention comparison showed that Group A achieved a mean difference of 2.316 points higher on the BBS compared to Group B ($t = 5.2171$, $p < 0.05$). Similarly, the reduction in TUG scores was more pronounced in the VR group, with participants finishing the test 2.07 seconds faster on average than those in the blindfolded group ($t = 4.6720$, $p < 0.05$). This suggests that the interactive and immersive nature of VR-based training facilitates a more robust enhancement of functional balance and mobility than visual occlusion alone.

Table 4. Improvement Scores Between-Groups

Parameter	Mean Difference (Group A vs B)	Combined SD	Calculated t-value	Critical t-value	Statistical Significance
Berg Balance Scale	2.316	7.141	5.2171	2.048	Significant (p < 0.05)
Timed Up and Go	2.070	6.178	4.6720	2.048	Significant (p < 0.05)

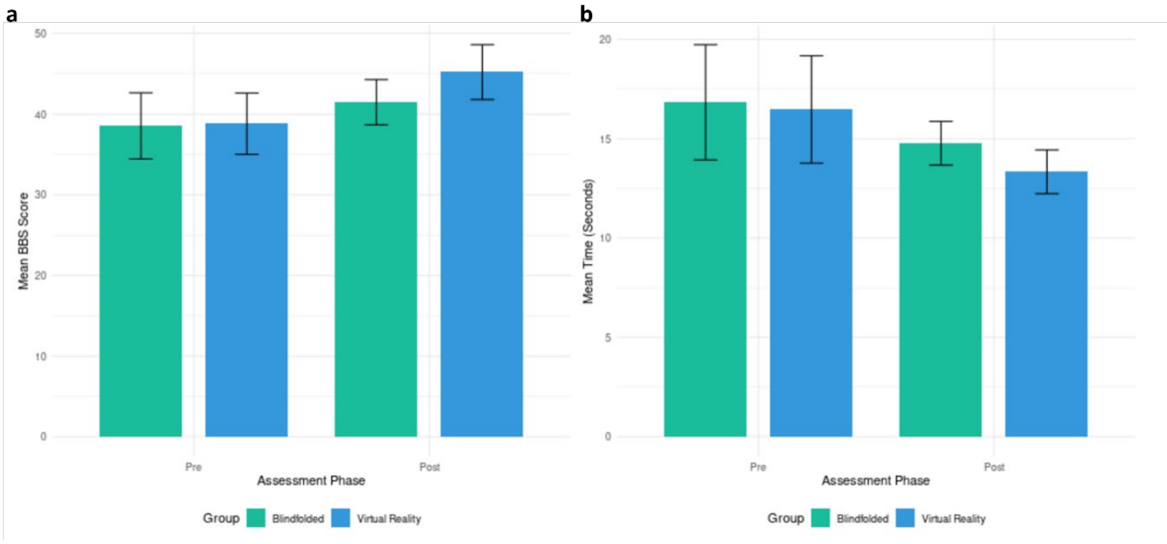

Figure 4. Improvement in a. Postural Stability (BBS) and b. Functional Mobility (TUG)

3.4. Safety, Compliance, and Adverse Events

The intervention protocols were well-tolerated, with a compliance rate exceeding 95% in both groups. No significant adverse events or injuries were reported during the study. A few participants in Group B noted transient dizziness during the initial blindfolded sessions, but these symptoms subsided as they acclimated to the protocol. The absence of falls during the training sessions indicates that both high-tech and low-tech sensory interventions can be safely implemented in clinical settings for patients with moderate Parkinson's disease.

Table 5. Results of Adherence Rates and Safety

Safety and Compliance Metric	Group A (VR)	Group B (BBT)
Total Compliance Rate	> 95%	> 95%
Reported Falls during Training	0	0
Instances of Transient Dizziness	0	2 (13.3%)
Program Attrition (Dropouts)	0	0
Reported Patient Engagement	High / Enthusiastic	Moderate / Confident

4. Discussion

The results of this work show that while both Virtual Reality (VR)-based training and Blindfolded Balance Training (BBT) are effective in improving postural stability and functional mobility, the VR cohort exhibited statistically superior outcomes. This disparity likely stems from the fundamentally different neurological mechanisms targeted by each modality. VR training provides an enriched multisensory environment, utilizing real-time visual-motor feedback to stimulate neuroplasticity. The interactive nature of the virtual environment encourages participants to engage in anticipatory postural adjustments, which are often impaired in individuals with Parkinson's disease [16]. VR may help bypass the dysfunctional basal ganglia circuitry, utilizing the motor cortex and cerebellum more effectively to regulate movement [17].

The significant improvements observed in the BBT group highlight the importance of sensory reweighting in neurorehabilitation. By occluding visual input, the central nervous system is compelled to rely on attenuated proprioceptive and vestibular signals [18]. In Parkinson's disease, patients often exhibit a pathological dependence on vision to compensate for kinesthetic deficits. BBT addresses this by forcing a recalibration of internal balance representations, which can improve static stability and body awareness. However, the lack of dynamic, task-specific feedback in a blindfolded state may explain why this group achieved smaller gains in mobility-specific tests like the TUG compared to the VR group [19].

A critical factor in the superior performance of the VR group is the level of cognitive engagement. Traditional exercises can often become repetitive, leading to diminished motivation. In contrast, VR incorporates elements of gamification and goal-oriented tasks that maintain high levels of participant interest [20]. This increased engagement is associated with greater dopamine release and enhanced motor learning, which are vital for long-term functional recovery in neurodegenerative conditions. VR allows for the safe simulation of complex, high-risk scenarios, such as navigating a crowded street, which translates more effectively to daily life activities than isolated balance drills [21].

These results indicate that a hierarchical approach to sensory training may be beneficial. While VR offers the most robust improvements, BBT remains a highly accessible, low-cost intervention that can be implemented in resource-limited settings. Integrating both modalities perhaps starting with BBT to improve internal sensory awareness before progressing to VR for complex environmental navigation could provide a more holistic rehabilitation strategy. This dual strategy would target both the sensory reweighting deficits and the executive motor planning issues characteristic of moderate-stage parkinsonism [22].

5. Conclusion

Both immersive Virtual Reality-based training and Blindfolded Balance Training serve as effective adjuncts to conventional physiotherapy in enhancing postural control and functional mobility for individuals with Parkinson's disease. However, the interactive and feedback-rich nature of Virtual Reality appears to elicit more substantial motor improvements, particularly in dynamic mobility tasks. VR-based systems provide a superior therapeutic stimulus through enriched visual-motor integration, while the blindfolded training offers a valuable alternative for promoting proprioceptive reliance. These results suggest the inclusion of targeted sensory training protocols within neurological rehabilitation to optimize functional independence and reduce the risk of falls in this population.

Compliance with Ethical Standards

Acknowledgements

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Conflict of Interest

All authors declare that they have no potential conflicts of interest or competing financial interests regarding the publication of this manuscript. There are no affiliations with or involvement in any organization or entity with a financial interest in the subject matter or materials (including Virtual Reality systems or specific rehabilitation equipment) discussed in this paper. This research was conducted independently, and the findings were not influenced by any commercial interests.

Statement of Ethical Approval

The experimental protocol for this research, which involved functional balance and mobility assessments in human participants, was reviewed and formally approved by the Institutional Ethics Committee (IEC) of Sri Ramakrishna Hospital and Institute of Paramedical Sciences (Protocol Approval No: COPT/MPT/ETHICS/06/2024). All clinical procedures were conducted in strict accordance with the ethical standards of the institutional research committee and the 1964 Helsinki Declaration and its later amendments. The study was carried out under the direct supervision of qualified physiotherapy researchers and neurologists.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in this study. Prior to enrollment, each participant was provided with a detailed explanation of the intervention protocols, including the Virtual Reality and Blindfolded Balance Training procedures. Participants were informed of their right to withdraw from the study at any time without any impact on their ongoing clinical care.

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