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Review

The Use of Virtual Reality to Improve Gait and Balance in Patients with Parkinson's Disease: A Scoping Review

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Abstract: (1) Background: Parkinson's disease (PD) is a progressive neurodegenerative disorder that impairs balance and postural control, gait, overall motor function, and mood, and involves the gradual degradation of several physiologic systems. With limited treatments available, physical therapy (PT)-based exercise is the nonpharmacologic measure of choice. There is a growing interest in using virtual reality (VR) gaming when rehabilitating patients with various acute brain injuries and neurological disorders. The purpose of this scoping review was to examine randomized controlled trials comparing VR-based rehabilitation programs versus traditional PT at improving gait and balance. (2) Methods: PubMed, CINAHL, and the Cochrane Central Register of Controlled Trials databases were searched using medical subject headings. Included studies were randomized controlled trials comparing VR intervention versus traditional PT in patients with PD and were published between 2013 and 2025. (3) Results: Eleven studies were reviewed and results in outcome measures (e.g., Berg Balance Scale, Unified Parkinson's Disease Rating Scale, and the Dynamic Gait Index) were compared between groups. Results of these studies demonstrated that patients receiving VR interventions had similar improvements to those in the traditional PT groups. In several studies, patients receiving VR intervention had superior outcomes. (4) Conclusion: VR is a promising addition to traditional PT and should be considered for patients with PD.

Keywords: balance; gait; motor function; physical therapy; quality of life; rehabilitation

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Academic Editor: Christos J. Bouras

Received: 8 March 2025
Revised: 26 March 2025
Accepted: 1 April 2025
Published: 5 April 2025

Citation: Surridge, R.; Stilp, C.; Johnson, C.; Brumitt, J. The Use of Virtual Reality to Improve Gait and Balance in Patients with Parkinson's Disease: A Scoping Review. *Virtual Worlds* **2025**, *4*, 13. https://doi.org/10.3390/virtualworlds4020013

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1. Introduction

Parkinson's disease (PD) is a common neurodegenerative disorder second only to Alzheimer's disease in prevalence [1]. The prevalence of PD increases with age, with the highest rates found in those 80 years of age and older [2,3]. Worldwide prevalence of PD is expected to rise to 12 million by 2050 [4]. PD is a progressive movement disorder that impacts balance and postural control, gait, overall motor function, mood, and involves the gradual degradation of several physiologic systems [2]. Patients diagnosed with PD present with characteristic symptoms such as bradykinesia, resting tremor, muscular rigidity, loss of postural reflexes, pain, fatigue, dementia, and depression [2]. This population is at an increased risk for falls, with over two-thirds sustaining at least one fall per year [5]. This diagnosis is difficult to treat, with limited pharmacologic and surgical options.

Medications, while beneficial for the classic motor symptoms of PD, have a range of side effects including nausea, vomiting, and orthostatic hypotension, and, with chronic

treatment, are associated with the development of motor complications [6]. In symptomatic patients, these complications manifest as fluctuations in motor abilities, occurring throughout the day with individuals experiencing "on" and "off" states (i.e., periods of decreased responsiveness to pharmacologic treatment) [2]. During an off state, the patient is at an increased risk of falling. This lends itself to hesitancy and fear surrounding mobility, subsequently causing a loss of muscle mass over time.

To reduce "off" time and treat tremor and dyskinesias, patients may pursue surgical intervention with deep brain stimulation (DBS) [6]. While DBS can provide dramatic results, it is primarily indicated for patients with disability from medication-induced motor complications. Side effects may also be severe, resulting from the surgical procedure itself (e.g., hemorrhage, infarction, infection) or from the electric stimulation (e.g., ocular and speech anomalies, muscle spasm, paresthesia, depression) [6].

Supervised physical therapy is the most effective nonpharmacological intervention associated with improvements in gait, balance, and decreasing fall risk [1,2,7,8]. Recently there has been interest in incorporating virtual reality (VR) and exergames into physical therapy services for improving movement outcomes (e.g., improving balance and gait) [9,10]. VR is defined as "a computer-generated simulation of an environment that immerses users in a lifelike experience" [11]. Exergaming is the term describing one exercising while playing a video game. Exergaming promotes physical activity by requiring "players" (i.e., patients) to move during gameplay. The use of VR helps to enhance the patient's experience and participation [12,13]. The VR environment can be immersive or non-immersive. Immersive VR utilizes VR headsets to "insert" the patient into the virtual world, whereas a non-immersive VR experience utilizes traditional devices and screens [14]. Real-time motion detection in combination with engaging video games helps motivate patients to exercise and can be a quantifiable and reliable therapeutic tool [10]. Incorporating VR into physical therapy treatments has demonstrated benefits for patients with traumatic brain injuries, multiple sclerosis, cerebral palsy, and stroke [15–17]. These include improvements in gross physical movement, functional and purposeful movement, and cognitive function [18–20].

Prior review studies have highlighted the potential value of including VR in a physical therapy program to improve gait or balance in patients with PD [15,21–24]. However, prior review articles have included populations other than PD, patients with PD and additional neurologic comorbidities, patient populations who received treatment via telehealth or in the home, and/or the inclusion of non-randomized controlled trials [15,21–24]. Rapid technological advancements also warrant reviewing evidence and reporting updates. The primary purpose of this scoping review is to examine the available evidence from randomized controlled trials (RCTs) assessing whether the use of VR-based rehabilitation in a supervised setting is as effective in improving gait and balance in patients with PD when compared with traditional physical therapy. A secondary purpose is to present other potential benefits of exergaming (e.g., quality of life) reported in the RCTs selected for this review.

2. Materials and Methods

A scoping review methodology was utilized for this study. A scoping review methodology is indicated to identify evidence pertaining to the use of VR to improve balance and gait in patients with PD and to identify potential gaps in knowledge [25,26]. The use of VR technology is relatively new, with researchers exploring a variety of VR applications and utilizing an assortment of outcome measures to assess aspects of gait and balance. To ensure all reporting items were completed in this review, the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR)

checklist was utilized [27]. The protocol for this review was registered with the Open Science Framework (https://doi.org/10.17605/OSF.IO/2TBUF).

2.1. Search Strategy

An initial electronic search was conducted in August of 2024 using the Medline and CINAHL databases. A subsequent search was performed in March of 2025 using PubMed, CINAHL, and the Cochrane Central Register of Controlled Trials (Figure 1, Table 1). Search techniques utilized multiple keywords and the advanced search function which allowed for multiple iterations of the same keyword, filtering of articles to only include full text, and a select date range to include the past twelve years (1 January 2013–1 March 2025). This time period was selected to reflect the advancements in VR technology. This search strategy (Figure 1) and its results are presented in Table 1. Table 1 presents the search term strategy and number of identified citations. Keyword combination searches were performed in order, as presented in Table 1 (i.e., from top to bottom). Journal article titles and abstracts were reviewed if a search strategy presented less than 300 citations. All titles and abstracts from articles were screened for applicability to the inclusion criteria, and either removed or included in a full-text review based on their compliance. Two authors (RS, JB) reviewed articles for inclusion; there were no disagreements between the two reviewers.

Table 1. Search strategy (March 2025) using PubMed, CINAHL, and the Cochrane Central Register of Controlled Trials databases.

Search Term	Identified Articles	Articles Included in This Review
Parkinson's disease OR Parkinson's AND virtual reality OR VR OR augmented reality OR exergaming AND randomized controlled trials	1756	Not assessed
Parkinson's disease OR Parkinson's AND virtual reality OR VR OR augmented reality OR exergaming AND gait AND balance	181	6 [28–33]
Virtual reality AND rehabilitation AND gait AND balance	84	0
Parkinson's disease OR Parkinson's AND virtual reality AND randomized controlled trials	84	4 [1,34–36]
Parkinson's disease AND rehabilitation AND virtual reality	39	1 [37]
Parkinson's disease AND physical therapy AND virtual reality	27	0
Parkinson's disease AND exercise AND virtual reality	26	0
Parkinson's disease AND exergaming	19	0
Parkinson's disease AND augmented reality	8	0

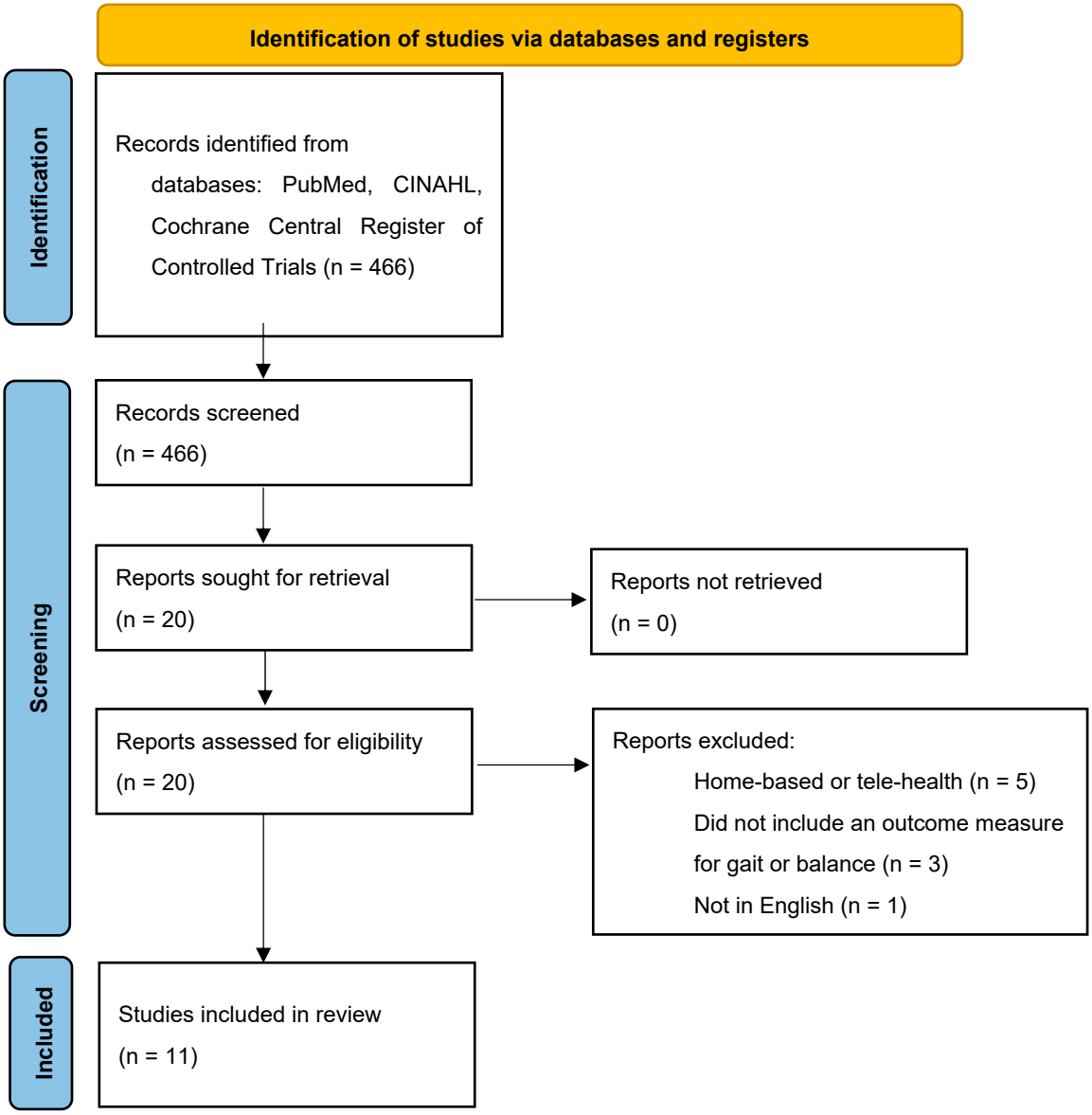


Figure 1. PRISMA flow diagram of studies included in this review.

2.2. Inclusion Criteria

A study was included in this scoping review if it was an RCT consisting of patients with a diagnosis of PD and who were allocated to either a non-VR (i.e., traditional physical therapy) group or a VR-based group. Included studies utilized various outcome measures to assess factors related to gait and balance. All included studies were published in peer-reviewed journals between 2013 and March 1st of 2025. A study was excluded if it included patients who had an additional neurologic disease comorbidity, did not have outcome measures for both gait and balance, was not a randomized controlled trial, was an abstract, was not published in English, or lacked in-person supervision (i.e., no telehealth or home-based interventions).

3. Results

3.1. Search Results

The literature search process yielded 466 results. Manual screening of titles and abstracts was performed, yielding 20 articles, which were then assessed. Upon a full-text assessment, 9 articles were excluded, leaving a total of 11 articles that were included in

this research Figure 1. A data extraction table was independently developed to present the characteristics of the studies chosen Table 2.

Table 2. Data extraction of study characteristics.

Reference	Year	Country	Subject Population	Sample Size
Liao et al. [34]	2015	Taiwan	(17M, 19F), mean age range 64.6 ± 8.6 y to 67.3 ± 7.1 y (group mean not provided), disease duration range 6.4 ± 3.0 y to 7.9 ± 2.7 y (group mean not provided), no baseline UPDRS	36
Mirelman et al. [35]	2016	Israel, Belgium, Italy, Netherlands, UK	(182M, 100F), mean age range 73.3 ± 6.4 y to 74.2 ± 6.9 y (group mean not provided), disease duration range not reported, no baseline UPDRS	282
Shih et al. [37]	2016	Taiwan	(16M, 4F), mean age 68.15 ± 9.82 y, disease duration 4.62 ± 4.30 y, no baseline UPDRS	20
Feng et al. [28]	2019	China	(17M, 13F), mean age 67.2± 4.72 y, disease duration 6.84± 1.45 y, baseline UPDRS 24.93 ± 6.81	28
Santos et al. [29]	2019	Brazil	(31M, 14F), mean age 64.3 ± 8.5 y, disease duration 7.1 ± 0.5 y, no baseline UPDRS	45
Bekkers et al. [30]	2020	Israel, Belgium, Italy, Netherlands, UK	(74M, 47F), mean age range 70.57 ± 6.04 y (FOG+) to 71.66 ± 6.3 y (FOG-) (group mean not provided), disease duration range 7.25 ± 5.1 y (FOG-) to 10.43 ± 6.7 y (FOG+) (group mean not provided), baseline UPDRS-III range 26.11 ± 12.2 (FOG-) to 31.83 ± 13.2 (FOG+)	121
Pazzaglia et al. [31]	2020	Italy	(35M, 16F), mean age 71 ± 8.5 y, disease duration 6.1 ± 6.29 y, baseline UPDRS 24 ± 1	51
Kashif et al. [1]	2022	Pakistan	(25M, 19F), mean age 63.09 ± 4.59 y, disease duration 6.39± 1.77 y, no baseline UPDRS	44
Maranesi et al. [32]	2022	Italy	(15M, 15F), mean age 74.1 ± 5.85 y, no baseline UPDRS	30
Gulcan et al. [33]	2023	Turkey	(26M, 4F), mean age 60.5± 6.0 y, disease duration 6.0 ± 4.5 y, no baseline UPDRS	30
Kashif et al. [36]	2024	Pakistan	(33M, 27F), mean age 63.33 ± 4.86 y, disease duration 6.43 ± 1.95 y, baseline UPDRS 33.23 ± 3.23	60

UPDRS—Unified Parkinson's Disease Rating Scale; M—male; F—female; y—years.

3.2. Major Findings

Results across the majority of studies demonstrated positive outcomes in disability measures, with subjects in the VR groups frequently experiencing greater improvements in outcome measures than the traditional physical therapy groups [1,28–37]. The following section summarizes the changes in balance, gait, quality of life, and motor function observed in the subjects who received either traditional physical therapy or the VR intervention. Table 3 presents the features of studies included in this review.

Table 3. Summary of the studies.

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Liao et al., 2015 [34]	60 min program consisting of 10 min of stretching exercises, 15 min of strengthening exercises, 20 min of balance exercises, and 15 min of treadmill walking 2 days a week for 6 weeks. Treadmill training was performed using a safety harness with subjects walking at 80% of their walking speed for the first 5 min, then increasing every 5 min by 0.2 km/h.	60 min program consisting of 45 min of exercise using the Wii Fit and 15 min of treadmill walking. The Wii Fit program consisted of 10 min of yoga exercises, 15 min of strengthening exercises, and 20 min of balance exercises. The treadmill training program was the same as the one performed by the traditional physical therapy intervention group.	Obstacle crossing performance, dynamic balance performance, SOT, PDQ-39, FES-I, TUGT.	At 6 weeks and 1 month after completing training: significant improvement in each group; however, no between group differences for obstacle crossing performance, TUGT, SOT, PDQ-39, FES-I. Significant between group differences, with VR group demonstrating greater improvements in dynamic balance at 6 weeks and 1 month after completing training: maximum velocity (forward): $p < 0.001$; $p < 0.001$; maximum velocity (sideward): $p < 0.001$; $p < 0.001$.	VR training program was as effective as the traditional PT program for many variables. VR training was superior than traditional PT for improving forward and sideward maximal velocity during dynamic balance testing.
Mirelman et al., 2016 [35]	45 min treadmill program performed 3 times a week for 6 weeks.	45 min treadmill training program with VR system. VR system utilized Microsoft Kinect camera that provided real-time feedback to the patient. Program performed three times a week for six weeks.	Incident rate of falls, short physical performance battery (SPPB), 2 min walk test, leading foot clearance, gait speed, SF-36	At 6 months: significantly lower rate of falls in the VR group: $p = 0.01$. Significantly greater improvements in SPPB gait, gait speed variability during obstacle negotiation, and 2 min walk test (at 6 weeks); SPPB total, SPPB balance, and leading foot clearance (at 6 months).	The VR-based treadmill program was superior to the traditional PT treadmill program at reducing the rate of falls. VR intervention superior at improving some measures of balance and gait.

Table 3. *Cont.*

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Shih et al., 2016 [37]	50 min conventional balance training (warm up, reaching activities, weight-shifting activities, marching activities, cool down) 2 days per week for 8 weeks	10 min warm up, 30 min balance-based exergaming with the Kinect sensor (stationary object reaching, moving object reaching, obstacle avoidance, and marching), and 10 min cool down 2 days per week for 8 weeks.	Limits of stability and one-leg stance for postural control, BBS for balance, and TUGT for gait and balance.	At 8 weeks, BBS and TUGT were improved significantly in both groups. Only the VR group showed significant improvement in postural control (limits of stability and one-leg stance).	Both training programs were effective at improving BBS and TUGT scores. The VR group was superior at improving limits of stability and one-leg stance measures.
Feng et al., 2019 [28]	45 min traditional rehabilitation training (warm up, balance training, physical conditioning to include rhythm training, coordination training, and cool down), 5 times per week for 12 weeks	45 min VR training (warm up, hands and feet touch the ball, hard boating, take the maze, and cool down) 5 times per week for 12 weeks.	BBS for balance, TUGT for gait and balance, UPDRS-III for motor function, and FGA for gait.	At 12 weeks, statistically significant improvements in BBS, TUGT, and FGA scores occurred in both the VR and traditional PT groups. UPDRS-III scores only improved in the VR group. VR group scores after training were significantly greater than traditional PT group scores: BBS: p-value < 0.05. TUGT: p-value < 0.05. UPDRS-III: p-value < 0.05. FGA: p-value < 0.05.	Both groups experienced significant improvements in BBS, TUGT, and FGA scores; however, the improvements were greater in the VR group. VR group also had significant improvements in UPDRS-III scores.

Table 3. *Cont.*

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Santos et al., 2019 [29]	40 min sessions performed twice a week for 8 weeks consisting of proprioceptive neuromuscular facilitation patterns and gait training consisting of manual resistance applied to the hip by the physical therapist when stepping.	Group 1: 40 min VR program (2x a week for 8 weeks) consisting of playing four games (boxing, soccer heading, golf, running) with the Nintendo Wii and Wii Balance Board. Group 2: 40 min combination (VR and traditional exercise); 20 min of Wii gaming and 20 min of traditional exercise. Performed twice a week for eight weeks.	BBS, DGI, TUGT, PDQ-39.	Each group experienced significant improvements in all outcome measures; however, there was no difference between groups. The effect size for each outcome measure was highest in the VR plus exercise group.	The VR and VR plus traditional exercise was as effective as the traditional PT group at improving measures of gait, balance, and PDQ-39 scores.
Bekkers et al., 2020 [30]	45 min treadmill program performed 3 times a week for 6 weeks.	45 min treadmill training program with VR system. VR system utilized Microsoft Kinect camera that provided real-time feedback to the patient. Program performed 3 times a week for six weeks.	Mini-BEST, NFOG-Q, SPPB, FSST, TMT-B, FES-I, PASE.	Both groups experienced significant improvements in Mini-BEST and TMT-B scores at 6 weeks ($p = 0.001$). Both groups demonstrated improved overall mobility performance in SPPB scores, with scores generally higher in the VR group ($p = 0.001$). Patients who were FOG+ and FOG− who were in the VR group had a greater reduction of falls ($p = 0.008$).	VR training was as good as traditional PT at improving Mini-BEST and TMT-B scores in the short-term. VR training reduced falls in those who were FOG+ or FOG- more than the traditional PT group.

Table 3. *Cont.*

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Pazzaglia et al., 2020 [31]	40 min conventional rehabilitation program (warm-up phase, active phase both standing and seated to include motor coordination/balance/walking, cool-down phase seated) 3 times per week for 6 weeks.	40 min VR rehabilitation with the NIRVANA system (7 exercises involving coordination of the lower and upper limbs, and trunk control, such as leading a dog, tapping falling leaves, and maintaining balance between two projected bars) 3 times per week for 6 weeks.	BBS for balance, DGI for gait response, DASH for upper limb performance, and SF-36 for quality of life.	At 6 weeks, there was statistically significant improvement in BBS, DGI, DASH, and the mental composite score (MCS) of the SF-36 in the VR group, and only statistically significant improvement in the DASH score in the traditional PT group: BBS: p-value = 0.003. DGI: p-value = 0.003. DASH: traditional PT p-value = 0.007, VR p-value = 0.009. MCS (SF-36): p-value = 0.037.	The VR program was more effective than the traditional PT program for improving a variety of outcome scores.
Kashif et al., 2022 [1]	40 min routine PT (warm-up, stretching, strengthening, limb coordination, core, neck, and gait training, relaxation), 20 min walking and cycling 3 days per week for 12 weeks.	40 min routine PT, 10–15 min of VR training with Wii Fit (tennis, boxing, bowling, soccer, kicking, table tilt, penguin slide, tilt city, single-leg extension, torso twist), and 5–10 min of MI techniques (watching and analyzing videos of a normal movement and a video of the patient performing the movement, visualizing and meditating on the movement, then performing the movement) 3 days per week for 12 weeks.	UPDRS-III for motor function, BBS for balance, ABC for balance confidence, UPDRS-II for ADLs.	At 12 weeks, statistically significant improvements in the VR group and traditional PT group were noted, with significant group main effect: UPDRS-III: p-value < 0.001. BBS: p-value < 0.001. ABC: p-value < 0.001. UPDRS-II: p-value < 0.001.	The VR group was significantly better at improving balance and function scores.

Table 3. *Cont.*

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Maranesi et al., 2022 [32]	50 min traditional therapy (breathing and relaxation, task-oriented exercise, walking, stretching, static and dynamic balance, flexibility, and unilateral and contralateral coordination exercises) 2 times per week for 5 weeks.	30 min traditional therapy and 20 min of treatment with the Tymo VR system (one-dimensional or two-dimensional exergames where the patient's body is the joystick, including apple picking, the hot air balloon, and the labyrinth) 2 times per week for 5 weeks.	POMA scale (POMA balance, POMA gait, and POMA total), FES-I for fear of falling, BI for ADLs, gait speed, and SF-12 for quality of life.	At 5 weeks, there was a statistically significant improvement in POMA balance for each group, though VR group improved to a greater degree. The VR group also improved with statistical significance in the POMA total, and the mental component of the SF-12: POMA total: p-value = 0.010. POMA balance: traditional PT p-value = 0.017, VR p-value = 0.004. SF-12 mental (MCS-12): p-value = 0.022.	Subjects in the VR group experienced significantly greater gains in POMA balance, POMA total, and SF-12 (MCS-12) scores.

Table 3. *Cont.*

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Gulcan et al., 2023 [33]	60 min conventional training (supine exercise, sitting exercise, standing exercise, stretching, relaxation) 3 days per week for 6 weeks.	90 min augmented and virtual reality gait training using the C-Mill VR+, starting with a conventional warm up, AR/VR gait training (stepping stones, random stepping stones, obstacle avoidance, speed adaptation, slalom, monster game, balls track, auditory cueing, nature island, and the Italian Alps) and ending with stretching and relaxation, 3 days per week for 6 weeks.	BBS for balance, UPDRS-III for motor function, ABC for balance confidence, TUGT for gait and balance, double-leg stability test, single-leg stability test, step length, step width, stride length, stance duration, swing duration, and total double support duration.	At 6 weeks, both groups showed statistically significant improvement in UPDRS-III, BBS, ABC, step length, and stride length (p-value <0.001), with group main effect significant in the VR group for step length and stride length: Step length (m): right p-value = 0.001, left p-value = 0.005. Stride length (m): p-value = 0.001. In all other outcomes, only the VR group showed significant improvement: TUGT: p-value = 0.002. Double-leg stability: p-value = 0.036. Single-leg stability: p-value = 0.031. Step width (m): p-value = 0.010. Stance duration (s): p-value = 0.001. Swing duration (s): p-value = 0.003. Total double support duration (s): p-value = 0.011.	Subjects in the VR group experienced significantly greater gains in measures for gait and stability.

Table 3. *Cont.*

Reference	Traditional Physical Therapy Intervention	VR Intervention	Outcome Measurements	Results	Summary of Conclusions
Kashif et al., 2024 [37]	40 min routine physical therapy (warm-up, stretching, strength training, cool-down) and 20 min walking and cycling 3 days per week for 12 weeks	VR + RPT (Group A) 40 min routine physical therapy, 15–20 min of VR training with Wii Fit (tennis, bowling, boxing, kicking, table tilt, penguin slide, tilt city, soccer, torso twists, single-leg stance) 3 days per week for 12 weeks. MI+ RPT (Group B) 40 min routine physical therapy, 15–20 min of MI training (watching and analyzing videos of a normal movement and a video of the patient performing the movement, visualizing and meditating on the movement, then performing the movement) 3 days per week for 12 weeks.	UPDRS-III for motor function, ABCs for balance confidence, BBS for balance, and UPDRS-II for ADLs.	At 12 weeks, the VR + RPT group showed statistically significant results in all outcomes, versus the traditional PT group and the test MI + RPT group: UPDRS-III: p-value = 0.011. UPDRS-II: p-value = 0.000. ABCs: p-value = 0.010. BBS: p-value = 0.019.	Subjects in the VR group experienced greater gains in balance and functional scores compared with the traditional PT and MI + RPT groups.

SOT—Sensory Organization Test; BBS—Berg Balance Scale; UPDRS—Unified Parkinson's Disease Rating Scale; ABC—Activities-specific Balance Confidence Scale; 10-MWT—10 min Walk Test; DGI—Dynamic Gait Index; PDQ-39—Parkinson's Disease Questionnaire; TUGT—Timed Up-And-Go Test; FGA—Functional Gait Assessment; DASH—Disabilities of the Arm, Shoulder and Hand; SF-36/12—Short Form 36/12; POMA—Performance-Oriented Mobility Assessment; FES-I—Falls Efficacy Scale International; BI—Barthel Index; MI—Motor Imagery.

3.3. Characteristics of Outcome Measures

Several outcome measures were used across the studies to assess functional disability associated with PD. These tools are useful in describing the progression of the disease and tracking patient improvement (or lack thereof) with exercise. The Unified Parkinson's Disease Rating Scale (UPDRS) is primarily used by neurologists as the gold standard for establishing disease severity and tracking progression [38]. It comprises four sections. Sections 1 and 2 evaluate an individual's motor and nonmotor experiences of daily living, and impairments in these areas have been strongly correlated with decreases in quality of life [39]. Section 3 comprises the motor exam, which includes reactive balance and gait. Section 4 evaluates motor complications related to pharmacologic interventions [38]. UPDRS has excellent internal consistency, with high intra-class correlation coefficients and adequate inter-rater reliability [40]. The studies included in this research focus specifically on Sections 2 and 3 of the UPDRS.

The Berg Balance Scale (BBS) is a performance-based balance assessment that is used to assess static and dynamic balance and has been validated to evaluate fall risk in older adults and persons with PD [41]. A total of 56 points can be achieved with BBS, and persons scoring <45 are identified as at risk to fall [42]. A defined sensitivity and specificity for fall risk (0.64 and 0.67, respectively) exists for scores $\leq$52, which is the suggested cut-off score for people with PD [43]. BBS has excellent test–retest reliability, inter- and intra-rater reliability, and high content validity [41].

The Activities-specific Balance Confidence (ABC) Scale is a self-report questionnaire intended for all populations with a fall risk (PD, stroke, multiple sclerosis, elderly) and measures the patient's balance confidence on a percentage scale for 16 ambulatory activities [43]. A score of lower than 50% indicates a low level of physical functioning, while a score of <69% indicates that a person with PD is at risk of falling one or more times in the next 12 months [44,45]. ABC has a high internal consistency, excellent test–retest reliability, and adequate criterion and construct validity [44].

Other scales that are commonly utilized for evaluating balance and gait performance to assess fall risk include the Dynamic Gait Index (DGI), Timed Up-and-Go Test (TUGT), the Short Physical Performance Battery ((SPPB), which includes individual sections for gait, balance, and a total score section that evaluates mobility performance), and the Tinetti Performance-Oriented Mobility Assessment ((POMA), also with individual sections dedicated to gait and balance). Additionally, quality of life is assessed using the Short Form Survey (SF), which is a health-related quality of life measure. Disease-specific quality of life measures included the Parkinson's Disease Questionnaire (PDQ) and UPDRS-II [28,31,33,36,37].

The most frequently used disability outcome measure in the assessed studies was BBS [1,28,31,33,36,37]. BBS is a reliable and valid test for balance and correlates well with other functional scales that are directed at balance in patients with movement disability [41]. Several of the studies in this review used additional balance assessments, including ABC for balance confidence, TUGT for balance while standing and walking, POMA balance, and double- and single-leg stability tests [1,28,31–33,36]. Gait performance was assessed using multiple outcome measures, including 10-MWT for gait speed, DGI and FGA for dynamic gait response, TUGT (also utilized for gait in addition to balance), POMA gait, and gait speed [28,31–33,37]. Quality of life was assessed using UPDRS-II (for ADLs), PDQ-/39, and SF-12/36 [1,29,31,32,34–36]. Finally, UPDRS-III was used by most studies as a disease-specific measure of motor function, and it includes scores for reactive balance and gait performance in its overall rating [1,28,30,33,36].

3.4. Balance Outcomes

Seven out of eleven studies utilized BBS as an outcome measure, with all seven studies demonstrating significant improvement in the VR group at the end of their intervention. Two studies showed significant improvement in BBS in both groups, with the VR group improving more than the traditional physical therapy (PT) group [1,28]. In three of these studies, BBS was significantly improved in both groups [29,33,37]. The final two studies demonstrated that the VR group had significantly greater improvements in balance compared with the traditional physical therapy group [31,36]. The studies that demonstrated improvements in BBS using VR alone lasted between six and twelve weeks and utilized VR systems such as Wii Fit, NIRVANA, C-Mill, and Xbox Kinect [10,28,29,31,33,37].

Three studies utilized ABC to assess for balance confidence. Kashif et al. utilized a 12-week VR plus PT intervention versus routine physical therapy alone, and found statistically significant improvement in the VR + PT group only [31]. Another study lasting 12 weeks that compared traditional PT with a PT plus VR intervention resulted in significant improvement in ABC in both groups, but with a greater improvement noted in the VR group [1]. Lastly, a 6-week study found statistically significant improvements in both the conventional PT and VR groups, with no difference between groups [33].

TUGT was utilized as a measure of both balance and gait. Five studies reported statistically significant improvements in TUGT [29,33,34,37]. Four of those studies demonstrated improvement in both the traditional PT and VR groups, with one study identifying a significant group main effect in the VR group [28,29,34,37]. The study from Gulcan et al. had statistically significant improvement in TUGT only in the VR test group [33].

Only one study utilized the POMA scale for balance outcomes. The results showed that, while both the traditional PT and VR groups had statistically significant improvements in balance, the VR test group improved to a greater degree than traditional PT [32]. Similarly, one study utilized SPPB to assess balance and found that scores were only improved in the VR group [35]. Shih et al. found similar results, with the VR group outperforming the control group in one-leg stance, while Liao et al. saw the VR group improve more than the control group in dynamic balance (including maintaining their results as far as 6 months post-training) [28,30,34]. The study also utilized SOT, which demonstrated statistically significant improvement in both groups [34]. Scores on Mini-BEST were significantly improved in both the traditional and VR groups immediately post-trial, but were not maintained over time [30].

3.5. Gait Outcomes

DGI was used in two studies as a measurement of gait response, while 2-MWT, FGA, SPPB, NFOG-Q, fall incidence, and POMA were utilized separately in four other studies. Mirelman et al. assessed changes in gait using 2-MWT, focusing primarily on gait speed, and with the gait portion of the SPPB [35]. At the end of the 6-week program and for a further 6 months post-intervention, the VR group (n = 154) displayed significantly greater improvements in gait speed variability and in SPPB gait than the control group (n = 148) [35]. The study and one other also looked at fall incidence as a measure of gait improvement, with both finding that the VR training groups were able to lower their rate of falls more significantly than the traditional PT groups [30,35].

Between the two studies that utilized DGI as an outcome measure, one found statistically significant improvement in both the VR and control groups, while the other found only significant improvement in the VR group [29,31]. Feng et al. assessed improvements in gait using FGA [28]. Subjects who completed a 12-week VR program utilizing exercises targeted at load bearing, shifting center of gravity, and quick response had statistically greater improvement in FGA compared with the control group of routine PT [28]. Improve-

ments noted in gait utilizing the POMA balance portion and NFOG-Q were not statistically significant [30,32].

3.6. Quality of Life

Out of the eleven studies reviewed, two included UPDRS-II as an outcome measure. In the study by Kashif et al., both the PT and VR groups demonstrated significant improvements in UPDRS-II; however, the VR test group outperformed the PT group [1]. In a follow-up study from Kashif et al., only the VR + PT test group demonstrated statistically significant improvement in UPDRS-II [36]. An additional three studies utilized SF-36 and SF-12 for quality of life measures; scores were significantly improved in the VR groups only [31,32,35]. PDQ-39 was implemented in two studies, both showing significant improvements in both the VR and control groups, without any between-group differences [29,34].

3.7. Motor Function

Four studies employed UPDRS-III (the measure to establish the severity of impairments specific to PD) to assess motor function. One study found statistically significant improvements in both the PT and VR groups, but with a significant group main effect noted in the VR test group [1]. Kashif et al. and Feng et al. reported statistically significant improvement in UPDRS-III scores in the VR groups [28,36]. Gulcan et al. found that both the PT and VR groups showed statistically significant improvement in UPDRS-III without a group main effect [33]. As an additional measure of mobility performance, SPPB total scores were used by two studies: Mirelman et al. found significantly greater improvement in the SPPB total in the VR group only, and Bekkers et al. found that, while both the VR and traditional groups improved with statistical significance, scores in the SPPB total were generally higher in the VR group [30,35].

4. Discussion

Exercise and movement therapy are primary conservative interventions for PD treatment [7]. While the benefits of traditional PT are known, identifying new interventions that may improve outcomes is a priority [7]. As demonstrated by the randomized controlled trials included in this review, technology-delivered training can produce improvements that not only support balance and gait but other neurobiological changes such as enhanced motor function and quality of life. Balance, as assessed by BBS, ABC, and TUGT, was improved in the VR groups equally or more than in the PT groups [1,28,29,31,33,34,36,37]. Similarly, when assessing motor function with UPDRS-III and SPPB, the VR groups had equal or greater improvements than the PT groups [1,28,30,33,35,36]. Subjects in the VR groups also demonstrated significant improvements in gait, though results were more varied across studies. DGI, FGA, 2-MWT, and SPPB gait demonstrated greater improvement in the VR group in several studies (POMA did not show statistically significant outcomes) [28–32,35]. UPDRS-II and SF-12/36 to assess ADLs and quality of life were improved only in the VR group, while PDQ was improved equally in the VR and traditional PT groups [1,29,31,32,34–36].

A clinical practice guideline (CPG) for PD was developed by the American Physical Therapy Association, which aims to improve the physical therapist management of individuals with PD [7]. It provides practice recommendations based on current best evidence and encourages clinicians to use this evidence in their clinical decision making, while incorporating clinical expertise and the patient's wants and needs [7]. CPG places a high importance on aerobic exercise, balance training, external cueing, and gait training, along with a moderate level of importance on behavior change and telerehabilitation to improve

access to therapy [7]. When evaluating the potential of a new form of rehabilitation, such as VR and exergaming, it is important to consider these domains in order to provide the best possible therapeutic management for patients. According to CPG, there is a high level of importance on aerobic exercise, for which VR has not been considered in this population [7]. VR, however, can achieve gait and balance training, impacts behavioral change, and offers external cueing. VR rehabilitation is a promising tool for training gait and balance impairments for people with PD as it allows users to be engaged in a highly enriched environment with external stimuli and cues, and can give real-time feedback that is motivating and rewarding [32]. This is particularly valuable in PD as gameplay and/or parameters can be augmented to target specific movement impairments such as bradykinesia, decreased amplitude, and reaction times. In order for an intervention to be useful for patients with PD, it should be task-specific, progressive, variable, and challenging [33]. Exergaming programming offers each of these components and, in addition, can quantify a patient's functional status pre- and post-rehabilitation [28].

When considering making VR training a part of clinical practice, some primary concerns for implementation are entry cost and fall risk. Out of the eleven-included research articles, two studies utilized the Kinect system (Microsoft, Redmond, WA (USA) as their virtual reality training device, three studies employed the WiiFit (Nintendo, Kyoto, Japan), and the remaining studies used either the Tymo system (Tyromotion, Graz, Austria), the NIRVANA system (BTS Bioengineering, Garbagnate Milanese, Italy), the C-Mill VR+ (Motek Medical, Amsterdam, Netherlands), or a makeshift VR system similar to that of the WiiFit. Both the Xbox Kinect and WiiFit systems are relatively inexpensive and are readily available to the general public. A Kinect can be purchased for approximately USD 45 and a WiiFit for approximately USD 75, which creates ease of accessibility. The larger and more complex systems like Tymo, NIRVANA, and C-Mill do not have publicly available cost analyses and are only available to be purchased by professionals and companies; this creates a higher bar for entry.

The use of VR can be applied safely with the appropriate monitoring of participants. All VR interventions are conducted carefully and without incident. The C-Mill system has built-in safety features that include a gait harness, making it one of the safer options for patients but does not improve accessibility as it is a more complex system. All other training systems do not come with protective devices to lessen fall risk, though, in a clinic setting, they could be joined with gait belts or clinic harness systems under the supervision of a trained physical therapist. When considering systems like the Kinect or WiiFit, particularly for home use, there is a greater risk of falls, which may be a deterrent in implementing this type of training, particularly in patients with PD with poorer balance at baseline. Considering this, these systems may allow for more accessibility in the delivery of rehabilitation services if recommended and monitored by a physical therapist [7]. Overall, the use of VR in the rehabilitation for people with Parkinson's is a valuable tool, particularly when included within a physical therapy program as a means of supplementation.

4.1. Future Research

There are several areas for further research. Future studies should evaluate long-term outcomes associated with VR-based rehabilitation strategies. It is unknown whether the short-term use of VR training (e.g., six to eight weeks) contributes to clinically meaningful changes in gait and/or balance. Most of the studies reviewed for this scoping review had follow-up periods of two to three months. It is also unknown if a chronic utilization of VR-training is required to maintain improvements.

A head-to-head comparison of each VR technique, including availability and cost effectiveness, would be beneficial for practitioners when choosing the system that is right

for their patient population. It may also be valuable to include more immersive systems like HTC Vive and Oculus in future comparisons. Further studies may consider the use of a rate of perceived exertion (RPE) scale during both the control and test interventions to track subjective strain, as exercise intensity can modify the treatment efficacy for patients with PD.

In the world of PD rehabilitation, there are other intervention strategies (other than VR and PT) that involve external cueing and focus on reducing rigidity and improving gait and balance. These include boxing, Dance for PD, cycling, LSVT BIG, and PWR! Moves, which were not assessed in this study and may be used in future experimental groups in other RCTs, comparing outcomes against both VR and PT. This would be beneficial to help assess whether VR offers more effective external cueing and whether the reduction in rigidity/improvement in gait and balance is greater than in other specialized PD interventions.

The incorporation of VR technology may also benefit other symptoms associated with PD. The focus of this scoping review was to assess the role of VR on gross lower extremity motor function (i.e., balance and gait) in patients with PD; physical therapists in the United States are primarily responsible for administering treatments to improve these domains. However, it is important to highlight that physical therapists frequently work as part of an interdisciplinary team (i.e., medical providers, occupational therapists, speech language pathologists, and psychologists) when caring for those with PD. Future research should assess the inclusion of VR as part of a comprehensive rehabilitation program. The current research highlights the benefits of including VR in addressing upper extremity function (i.e., fine motor skills), psychological well-being, and speech [46–48].

4.2. Study Limitations

Several limitations were noted between studies that should be considered when assessing the results. The most prevalent study limitation was a small sample size, which can limit the strength of result interpretation [32–34,37]. Another common study limitation noted was either a very short follow-up period or no follow-up data at all. This was impactful, as the duration of improvement from VR rehabilitation was unknown [31,33,35]. The studies conducted by Shih et al. and Kashif et al. each noted that their patient populations did not include advanced PD stages (baseline performance in outcome measures was high), which can limit the assessment of the benefits of VR training [1,36,37]. Similarly, Santos et al. purported that, as patients with PD with depression were not screened prior to the study, more significant results may be absent due to baseline mental status, and findings cannot be generalized to the PD population as a whole [29]. Some final limitations to note were the variability of systems and their calibration, whether virtual exercises were representative of ADLs (a subjective measure, and was patient-dependent based on improvements achieved during a VR program), recall bias on self-reported questionnaires, and the lack of instrumental evaluation to assess balance and postural reactions [30,31,35,37].

Another study limitation across all included trials was the use of outcome measures. BBS, TUGT, ABC, and UPDRS-III all provide powerful psychometric estimations of balance, fall risk, and motor function [34]. However, there are other measures that have high prediction assessments that were utilized by very few studies analyzed in this research, particularly the Mini-Balance Evaluation Systems Test (Mini-BEST) and the Falls Efficacy Scale International (FESI), which have been proven to have strong psychometric validation [49]. Though these outcome measures are recommended for use and are strong in estimation, they are not, however, responsive to change over time. With PD having such a variable disease course, more research is needed in this area [49].

5. Conclusions

PD is a multifaceted illness with varied needs for rehabilitation. Overall, virtual reality exergaming has been shown to be as effective as traditional physical therapy in improving components of gait and balance. In some cases, patients who received the VR-based intervention had significantly better outcomes than those who received the non-VR intervention. Future research is warranted to determine the optimal applications of this technology. Clinicians should consider utilizing VR exergaming to improve balance and gait in patients with Parkinson's disease.

Author Contributions: Conceptualization, R.S. and J.B.; methodology, R.S. and J.B.; formal analysis, R.S., C.S., C.J., and J.B.; investigation, R.S.; writing—original draft preparation, R.S.; writing—review and editing, R.S., C.S., C.J., and J.B.; supervision, C.S., C.J., and J.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PD	Parkinson's Disease
VR	Virtual Reality
PT	Physical Therapy
BBS	Berg Balance Scale
UPDRS	Unified Parkinson's Disease Rating Scale
ABC	Activities-specific Balance Confidence Scale
10-MWT	10 min Walk Test
DGI	Dynamic Gait Index
PDQ	Parkinson's Disease Questionnaire
TUGT	Timed Up-And-Go Test
FGA	Functional Gait Assessment
DASH	Disabilities of the Arm, Shoulder and Hand
SF-36/12	Short Form 36/12
POMA	Performance-Oriented Mobility Assessment
FES	Falls Efficacy Scale
BI	Barthel Index
MI	Motor Imagery

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