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ORIGINAL ARTICLE

Effect of immersive VR therapy on Parkinson's: systematic review, meta-analysis, and sequential analysis

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Abstract

Objective: *To compare the efficacy of immersive virtual reality therapy (VRT) versus conventional physical therapy (CPT) in patients with Parkinson's disease (PD) through a systematic review and meta-analysis.* **Methods:** *Systematic searches were conducted in PubMed, Web of Science, and Scopus (PRISMA 2020). We included randomized controlled trials (RCTs) comparing immersive VRT and CPT in PD patients. Primary outcomes included balance, measured with the Berg Balance Scale (BBS); functional mobility, measured with the timed "Up and Go" test (TUGT); motor performance, measured with the Unified PD Rating Scale (UPDRS) part III; and fall risk, measured with the dynamic gait index (DGI). Meta-analyses used random-effects models to compute mean differences (MD) and 95% confidence intervals. Heterogeneity (I^2), publication bias, and trial sequential analysis (TSA) were assessed.* **Results:** *Four RCTs (n = 102) were analyzed. Immersive VRT showed favorable trends, particularly for mobility (TUGT) and balance (BBS). Balance (BBS): MD = 2.26 (–1.04, 5.55), p = 0.18, I^2 = 79%; TSA showed insufficient information size (required information size = 464). TUGT: MD = 0.09 (0.00, 0.17), p = 0.04, I^2 = 0%. UPDRS III: MD = –0.19 (–3.28, 2.90), p = 0.91, I^2 = 94%. DGI: MD = 1.39 (–0.23, 3.02), p = 0.09, I^2 = 0%.* **Conclusions:** *Immersive VRT may offer functional benefits for PD, yet current evidence is insufficient to draw firm conclusions. TSA indicates a high risk of type II error. Further high-quality RCTs with standardized protocols are needed.*

Keywords: *Immersive virtual reality. Parkinson's disease. Neurorehabilitation. Randomized controlled trials. Trial sequential analysis.*

Efecto de la terapia RV inmersiva en Parkinson: revisión sistemática, metaanálisis y análisis secuencial

Resumen

Objetivo: *Comparar la eficacia de la Terapia de Realidad Virtual Inmersiva (VRT) frente a la Terapia Física Convencional (CPT) en pacientes con enfermedad de Parkinson (EP) mediante una revisión sistemática y un metaanálisis.* **Métodos:** *Se realizaron búsquedas sistemáticas en PubMed, Web of Science y Scopus (PRISMA 2020). Se incluyeron ensayos clínicos aleatorizados (ECA) que compararan terapia de realidad virtual inmersiva (VRT) con fisioterapia convencional en pacientes con enfermedad de Parkinson. Los desenlaces primarios incluyeron equilibrio medido con la Berg Balance Scale, movilidad funcional evaluada con el Timed "Up and Go" Test, desempeño motor medido con la Unified Parkinson's Disease Rating Scale parte III, y riesgo de caídas medido con el Dynamic Gait Index. Los metaanálisis utilizaron modelos de efectos*

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aleatorios para calcular las diferencias de medias (DM) e intervalos de confianza (IC) del 95%. Se evaluaron la heterogeneidad (I^2), el sesgo de publicación y el Análisis Secuencial de Ensayos (TSA). **Resultados:** *Se analizaron cuatro ECA (n = 102). La VRT inmersiva mostró tendencias favorables, especialmente en movilidad (Timed "Up and Go" Test) y equilibrio (Berg Balance Scale), pero sin diferencias estadísticamente significativas. Equilibrio (BBS): MD = 2.26 (–1.04, 5.55), p = 0.18, I^2 = 79%; el TSA mostró un tamaño de información insuficiente (RIS = 464). TUGT: MD = 0.09 (0.00, 0.17), p = 0.04, I = 0%. UPDRS III: MD = –0.19 (–3.28, 2.90), p = 0.91, I^2 = 94%. DGI: MD = 1.39 (–0.23, 3.02), p = 0.09, I^2 = 0%.* **Conclusiones:** *La VRT inmersiva podría ofrecer beneficios funcionales para la EP, aunque la evidencia actual es insuficiente para establecer conclusiones firmes. El TSA indica un alto riesgo de error tipo II. Se necesitan más ECA de alta calidad con protocolos estandarizados.*

Palabras clave: *Realidad virtual inmersiva. Enfermedad de Parkinson. Neurorrehabilitación. Ensayos controlados aleatorizados. Análisis secuencial de ensayos.*

Introduction

Parkinson's disease (PD) is a chronic, progressive neurodegenerative condition characterized by motor impairments such as bradykinesia, rigidity, and postural instability, significantly reducing quality of life[1]. It affects over 10 million individuals worldwide, and its prevalence continues to rise with aging populations[2,3]. Motor rehabilitation in PD plays a crucial role in preserving functional independence, reducing fall risk, and improving quality of life – particularly in stages where pharmacological treatments become less effective against symptoms such as gait disturbances, postural instability, or freezing of gait. Increasing evidence suggests that physical exercise not only alleviates motor symptoms but may also positively influence disease progression through neuroplastic and neuroprotective mechanisms[4].

Conventional physical therapy (CPT) is routinely employed to address motor deficits, but outcomes are often suboptimal or short-lived[5]. Immersive virtual reality therapy (VRT), using interactive and adaptive digital platforms, has emerged as a promising tool to stimulate neuroplasticity and enhance motor function. VRT aligns with modern approaches to personalized rehabilitation by offering multisensory feedback and task-specific training, thereby enhancing both motor learning and therapeutic engagement[5,6]. Despite this potential, randomized trials yield inconsistent results, and no meta-analytical consensus has been established[4]. This systematic review and meta-analysis aimed to compare immersive VRT with CPT on balance, mobility, motor function, and fall risk in PD. We hypothesized that VRT would provide superior motor outcomes. Trial sequential analysis (TSA) was employed to assess whether current evidence is sufficient for clinical recommendations.

Materials and methods

Search methods

This systematic review adhered to the PRISMA 2020 guidelines. The PRISMA 2020 checklist can be found in Supplementary material 1. A comprehensive search was performed in PubMed, Web of Science, and Scopus databases, with no restrictions on language or publication date. The search strategy utilized the following terms and Boolean operators: ("Parkinson's Disease" AND "Virtual Rehabilitation" OR "Virtual Reality Therapy") AND ("Randomized Controlled Trial"). The complete search process is illustrated in the PRISMA flow diagram (Fig. 1). For additional details on the full search strategy, please refer to Supplementary material 2.

Inclusion and exclusion criteria

Eligible studies were randomized controlled trials (RCTs) comparing immersive VRT with CPT in patients with a clinical diagnosis of PD. Studies had to report at least one of the following outcomes: balance (Berg Balance scale [BBS]), mobility (timed "Up" and "Go" test [TUGT]), motor performance (Unified PD Rating Scale Part III [UPDRS III]), or fall risk (dynamic gait index [DGI]). Observational studies, studies without a control group, or those lacking sufficient data to estimate effect sizes were excluded. In addition, RCTs that included video games such as Wii™ or Nintendo™ (non-immersive) were also excluded.

Data extraction information

Two independent reviewers screened titles and abstracts (FLR and BGB), followed by a full-text review to determine study eligibility. Data extraction was performed using a standardized form, collecting

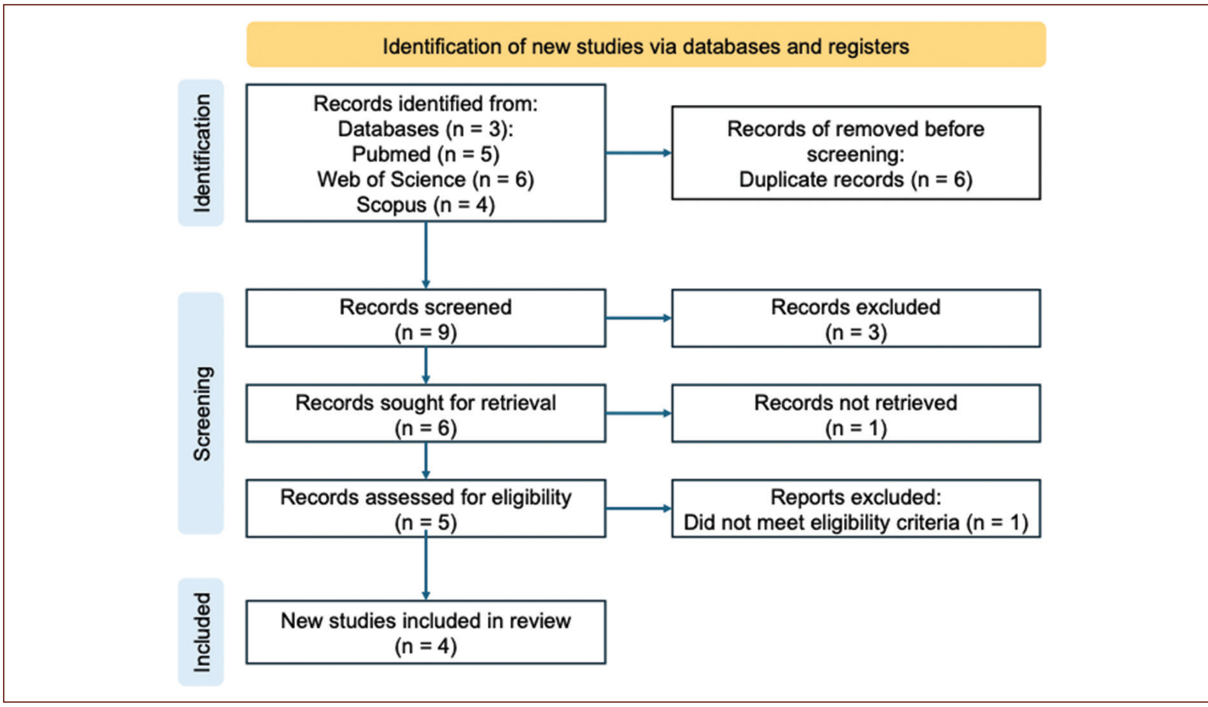

Figure 1. Prisma flowchart.

information on sample size, participant demographics (Table 1)[7-10], study design, intervention characteristics, duration, measured outcomes (Table 2)[7-10], and results included in the meta-analysis (Table 3)[7-10]. Disagreements between reviewers were resolved by consensus with an expert in movement disorders and research. Inter-rater agreement was assessed using Cohen's kappa coefficient to ensure reliability in study selection.

Quality assessment

The risk of bias for each included study was assessed using the Cochrane Risk of Bias 2.0 (RoB 2.0) tool (Fig. 2). For additional details on the full risk of bias assessment, please refer to Supplementary Material 2. The certainty of evidence for each outcome was evaluated using the grading of recommendations, assessment, development, and evaluation methodology. Meta-analyses were conducted using Review Manager (RevMan 5.4), applying a random-effects model to calculate mean differences (MD) with 95% confidence intervals (CI) for continuous variables. Heterogeneity was quantified using the I^2 statistic. Statistical significance was set at $p < 0.05$. Random-effects models assume that true effect sizes vary across studies and are approximately normally distributed around an overall mean effect. A sensitivity analysis was planned but not conducted due to the small number of included studies (n = 4), which limited the ability to meaningfully assess robustness. Publication bias was evaluated using funnel plots and Egger's test. To assess whether the cumulative evidence was sufficient, TSA was conducted using TSA software version 0.9.5.10 β, applying a two-sided α of 5%, β of 20%, and the minimal clinically important difference (MCID) as the anticipated effect size.

Results

Search results

A total of four RCTs were included[7-10], comprising a total of 102 participants with PD. These studies directly compared the effects of immersive VRT versus CPT on motor outcomes. The selection process followed PRISMA guidelines[11] and is detailed in the flow diagram (Fig. 1).

Patient characteristics

Participants across the included studies[7-10] had a mean age of 65.4 years. They were primarily classified within stages I to IV of the Hoehn and Yahr scale,

Table 1. Population demographics

Study	Population (n)			Age mean (IQR)		Male (n)			Female (n)		
	VRT	CPT	Total	VRT	CPT	VRT	CPT	Total	VRT	CPT	Total
Feng et al.[7]	14	14	28	67.47 ± 4.79	66.43 ± 4.64	8	9	17	7	6	13
Goffredo et al.[9]	49	48	97	67.8 ± 6.6	68.2 ± 5.8	27	24	49	22	24	48
Yang et al.[8]	11	12	23	72.5 ± 8.4	75.4 ± 6.3	7	7	14	4	5	9
Pazzaglia et al.[10]	25	26	51	72 ± 7	70 ± 10	18	17	35	7	9	16

VRT: virtual reality therapy; CTP: conventional physical therapy.

Table 2. Included articles characteristics

Study	Study design	n	Participants	Intervention	Duration	Measured outcomes
Feng et al.[7]	Single-blinded RCT	28	Adults with PD based on the UK Parkinson's Disease Society Brain Bank criteria. Hoehn and Yahr score 2.5-4	Virtual reality therapy Conventional physical therapy Sessions: 45 min, once a day, 5 times a week ON medication phase: intervention 2 h after medication	12 weeks	Berg Balance Scale, Timed "Up and Go" Test, UPDRS III, functional gait assessment
Goffredo et al.[9]	Single-blinded, Multicenter RCT	97	Adults with PD based on the UK Parkinson's Disease Society Brain Bank criteria. Hoehn and Yahr score ≤ 3	Virtual reality therapy Conventional physical therapy Sessions: 45 min once a day, 3-5 times a week ON medication phase: Intervention 1 h after medication	6 to 10 weeks	Timed "Up and Go" Test, UPDRS III, miniBEST test, 6 min walking test
Yang et al.[8]	Single-blinded RCT	23	Adults with PD based on the UK Parkinson's Disease Society Brain Bank criteria. Hoehn and Yahr 2-3	Virtual reality therapy Conventional Physical Therapy Sessions: 50 min once a day, twice a week ON medication phase: intervention 1 h after medication	6 weeks	Berg Balance Scale, Timed "Up and Go" test, UPDRS III, dynamic gait index, PDQ-39
Pazzaglia et al.[10]	Single-blinded, RCT	51	Adults with PD based on the Gelb criteria	Virtual reality therapy Conventional physical therapy Sessions: 40 min once a day, 3 times a week. On the medication phase: Intervention 2 h after medication	6 weeks	Berg Balance Scale, dynamic gait index, physical composite score (SF-36), mental composite score (SF-36), disabilities of the arm, shoulder, and hand scale

RCT: randomized controlled trial; PD: Parkinson's disease.

indicating mild-to-severe disease severity. The duration of the interventions ranged between 6 and 12 weeks. Baseline demographic and clinical characteristics were generally comparable between intervention and control groups, although small sample sizes limited subgroup analyses.

Statical analysis

In terms of balance, assessed using the BBS, the pooled MD was 2.26 with a 95% CI of –1.04-5.55, which was not statistically significant ($p = 0.18$). Considerable heterogeneity was observed ($I^2 = 79\%$), and

Table 3. Data included in the meta-analysis

Study	Berg balance scale				Timed "Up and Go" test				UPDRS III				Dynamic gait index			
	VRT		CTP		VRT		CTP		VRT		CTP		VRT		CTP	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Feng et al.[7]	6.07	0.35	1.93	0.7	3.29	0.94	2.71	0.97	3.64	1.25	3.36	1.93	NA	NA	NA	NA
Goffredo et al.[9]	NA	NA	NA	NA	−0.7	0.19	−0.78	0.23	−2.5	0.8	0.35	0.8	NA	NA	NA	NA
Yang et al.[8]	3.36	2.38	4.17	5.01	−3.34	3.67	−3.07	3.15	2.55	5.96	−3.17	8.73	4.09	2.98	3.17	2.86
Pazzaglia et al.[10]	3.6	2.38	0.8	7.41	NA	NA	NA	NA	NA	NA	NA	NA	1.6	4.47	−0.2	3,51

SD: standard deviation; VRT: virtual reality therapy; CTP: conventional physical therapy. NA: not available or not reported in the original publication.

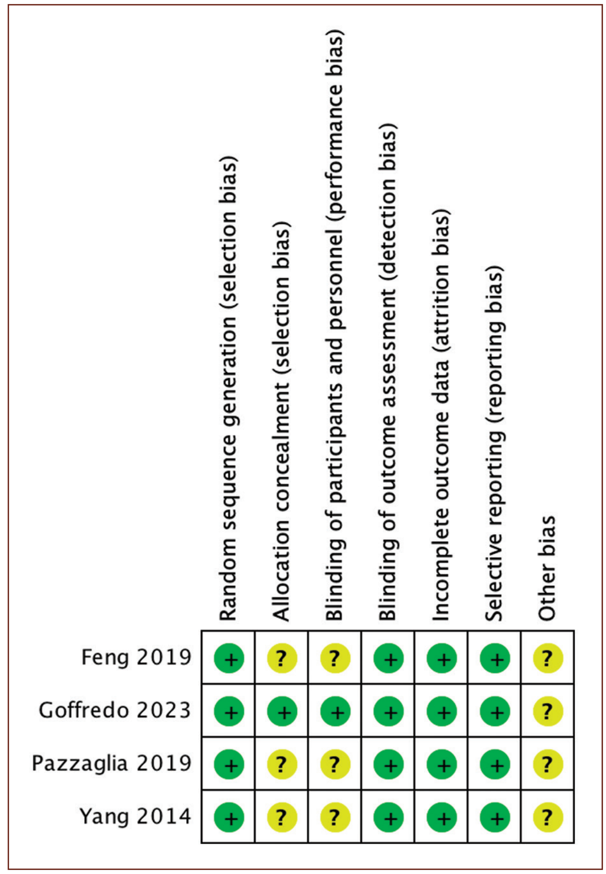

Figure 2. Risk of bias summary for included randomized controlled trials. Assessed using the Cochrane Risk of Bias Tool across seven domains. Symbols indicate low risk ("+"), unclear risk ("?"), or high risk ("–").

TSA confirmed that the required information size (RIS = 464) had not been reached, suggesting insufficient power for conclusive interpretation (Figs. 3 and 4). For functional mobility, evaluated with the TUGT, the pooled MD was 0.09 (0.00, 0.17), achieving statistical significance ($p = 0.04$) with no heterogeneity ($I^2 = 0\%$) (Fig. 5). The TUGT is a widely used clinical measure that assesses the time it takes for an individual to stand up from a chair, walk a short distance, turn, return, and sit down. It reflects functional mobility, which is critical for daily activities and fall prevention. In PD, impaired TUGT performance is strongly associated with higher fall risk and reduced independence, making even modest improvements potentially meaningful in clinical contexts. Regarding motor performance, as measured by the Unified PD Rating Scale Part III (UPDRS III), no significant difference was found between groups (MD = −0.19 [-3.28, 2.90], $p = 0.91$), with high heterogeneity ($I^2 = 94\%$) (Fig. 6). Considerable heterogeneity was observed ($I^2 = 79\%$). A subgroup analysis was

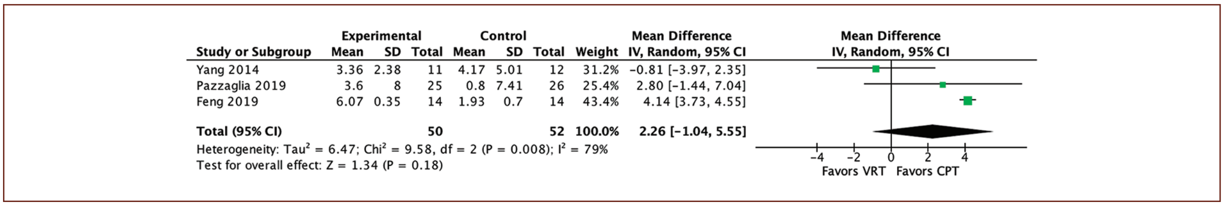

Figure 3. Forest plot of studies evaluating the effect of Virtual Reality Therapy (VRT) on balance using the Berg Balance Scale (BBS), compared to conventional physical therapy (CPT). The pooled mean difference was 2.26 [−1.04, 5.55], with no statistical significance (p = 0.18) and high heterogeneity (I^2 = 79%).

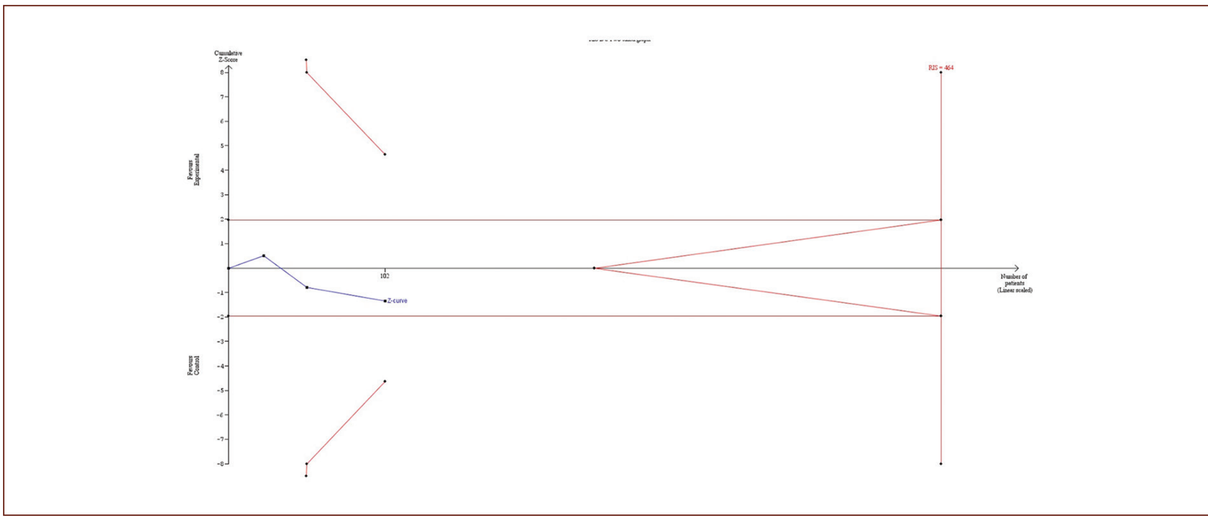

Figure 4. Trial Sequential Analysis (TSA) for the effect of Virtual Reality Therapy (VRT) on balance. The cumulative Z-curve did not cross any monitoring boundaries, and the required information size (RIS = 464 patients) was not reached, indicating that current evidence is insufficient to draw firm conclusions.

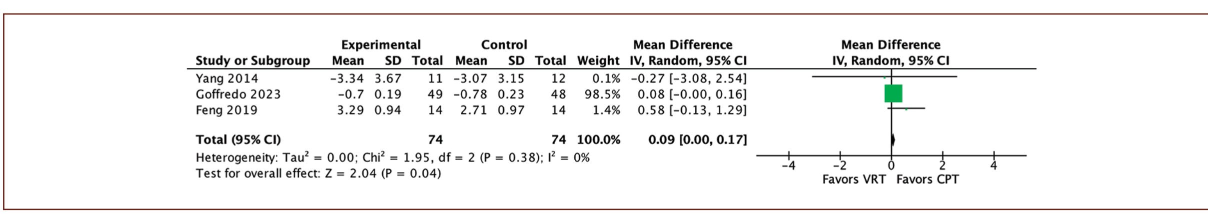

Figure 5. Forest plot of studies evaluating the effect of Virtual Reality Therapy (VRT) on functional mobility using the Timed Up and Go (TUG) test, compared to conventional physical therapy (CPT). The pooled mean difference was 0.09 [0.00, 0.17], with marginal statistical significance (p = 0.04) and no heterogeneity (I^2 = 0%).

performed to explore the sources of heterogeneity, suggesting that studies such as Feng 2019 in the BBS analysis and Yang 2014 in UPDRS III contributed substantially due to their extreme effect sizes. This variability likely stems from differences in intervention duration and the inclusion of patients at different stages of PD, which can influence responsiveness to therapy and lead to divergent outcomes. Finally, fall risk, assessed using the DGI, showed a non-significant trend favoring immersive VRT (MD = 1.39 [−0.23, 3.02], p = 0.09) with no observed heterogeneity (I^2 = 0%) (Fig. 7). No publication bias was detected upon funnel plot inspection and Egger's test. In general, the results suggest a modest but consistent

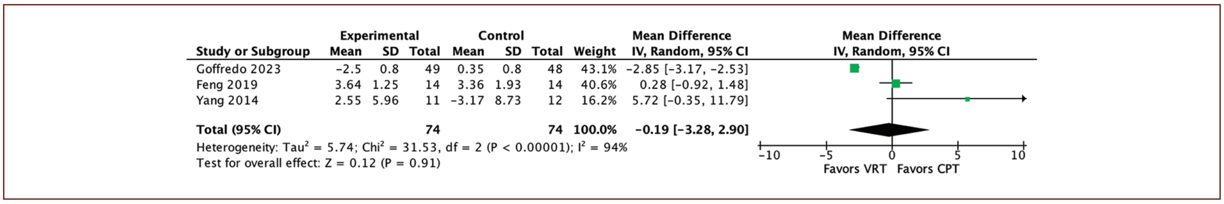

Figure 6. Forest plot of studies evaluating the effect of Virtual Reality Therapy (VRT) on motor performance using the Unified Parkinson's Disease Rating Scale Part 3 (UPDRS-III), compared to conventional physical therapy (CPT). The pooled mean difference was −0.19 [−3.28, 2.90], with no statistical significance (p = 0.91) and high heterogeneity (I^2 = 94%).

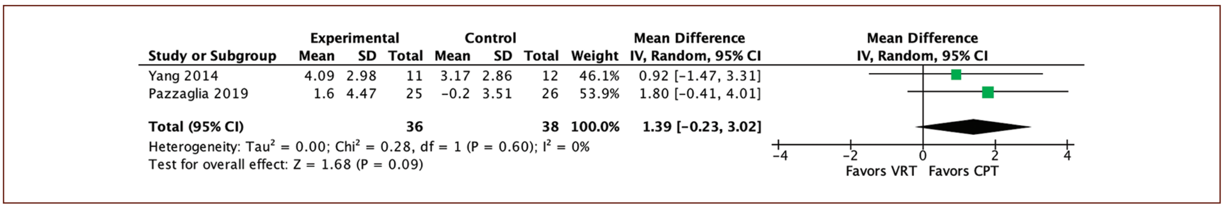

Figure 7. Forest plot of studies evaluating the effect of Virtual Reality Therapy (VRT) on fall risk, measured using the Dynamic Gait Index (DGI), compared to conventional physical therapy (CPT). A trend favoring VRT was observed (MD = 1.39 [−0.23, 3.02]), though it did not reach statistical significance (p = 0.09) and showed no heterogeneity (I^2 = 0%).

trend in favor of immersive VRT; however, the current body of evidence is underpowered and limited by statistical and clinical heterogeneity.

Discussion

This meta-analysis assessed the comparative efficacy of immersive VRT and CPT in PD motor rehabilitation. Although trends favored immersive VRT, only mobility (TUGT) reached statistical significance, and even then, the effect was marginal. Balance improved modestly with immersive VRT, but did not surpass the MCID of ~4 points on BBS. High heterogeneity in BBS and UPDRS III suggests protocol and population variability across studies. Mobility improvements were consistent and may reflect the motivational and task-specific nature of immersive VRT. Fall risk and motor scores did not show meaningful changes, possibly due to limited intervention duration or insufficient power. TSA confirmed the current sample size is underpowered, particularly for balance-related outcomes (Fig. 4). By assessing whether the accrued information is sufficient to draw firm conclusions, TSA helps prevent premature claims of benefit or lack of effect based on underpowered data. The finding that the Z-curve did not cross significance boundaries and that the RIS was not reached underscores the need for larger, well-designed trials to determine the true clinical impact of immersive VRT in PD rehabilitation.

Our findings align with previous narrative reviews suggesting the potential of immersive VRT[12-24] but insufficient high-quality evidence for routine implementation. Although several published meta-analyses have reported positive outcomes for VRT in PD[12,13,15-18,19,21,22], many of these include RCTs that rely on commercial video game systems such as Nintendo Wii™ (non-immersive). This methodological choice introduces a significant limitation, as these systems are not designed for therapeutic use and lack clinical calibration, reducing the reliability and translatability of the findings to real-world rehabilitation settings[25,26].

It is critical to differentiate clinically validated immersive VRT from entertainment-based gaming platforms. Immersive VRT is specifically developed for medical purposes, employing task-specific training, motion tracking, and customizable feedback to target motor deficits under professional supervision[26]. In contrast, devices such as the Wii™ or Nintendo™ consoles offer generic, non-adaptive experiences without therapeutic frameworks, progression protocols, or outcome standardization[26]. Their use may enhance patient engagement superficially, but it does not fulfill the principles of evidence-based rehabilitation[25,26]. Therefore, RCTs incorporating such systems were deliberately excluded from the present meta-analysis. Including them would compromise the methodological rigor and distort the clinical relevance of the conclusions, given the fundamental differences in design, intensity, and neurorehabilitative value between commercial gaming and structured immersive VRT.

Immersive VRT should not be viewed as a replacement, but rather as an evolution of traditional rehabilitation paradigms. Its integration into clinical practice holds the potential to deliver structured, adaptive training protocols that respond to individual motor phenotypes, disease stage, and symptom dynamics. Investigating its efficacy through well-designed RCTs is therefore not only an important methodological consideration but also a fundamental step toward precision medicine in PD rehabilitation.

Limitations include the small overall sample size, variability in intervention protocols and duration, and lack of long-term follow-up data. In addition, the included RCTs enrolled participants at different stages of PD (Hoehn and Yahr scores), introducing potential selection bias and heterogeneity in baseline characteristics that could influence treatment response. The risk of type II error also remains due to underpowered analyses in some outcomes. Future research should prioritize multicenter RCTs with standardized immersive VRT protocols, well-defined and robust control groups, and extended follow-up periods to assess the sustainability of effects. Economic evaluations and studies examining adherence and accessibility in diverse settings are also warranted to support implementation in clinical practice.

Conclusion

This meta-analysis demonstrates trends suggesting possible benefits in mobility, though not in balance or overall motor severity. These findings highlight the potential role of immersive VRT as an adjunct in PD rehabilitation, while underscoring the need for larger, well-designed trials to confirm its clinical effectiveness across different motor domains.

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The authors declare that this work was carried out with the authors' resources.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical considerations

Protection of human subjects and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality, informed consent, and ethical approval. This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

Declaration on the use of artificial intelligence (AI). The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

Supplementary data

Supplementary data are available at DOI: 10.24875/RMN.25000019. These data are provided by the corresponding author and published online for the benefit of the reader. The contents of supplementary data are the sole responsibility of the authors.

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