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Evaluating the Gross Motor Function and Balance in Children with Cerebral Palsy: A Systematic Review and Meta-analysis

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ABSTRACT
Background: *Cerebral palsy (CP) is a leading cause of childhood physical disability, with impairments in gross motor function and balance that limit independence and participation. A wide range of physical therapy (PT) approaches has been proposed, but comparative evidence across intervention types and functional severity levels remains fragmented.* ***Objective***: *To synthesize randomized controlled trial (RCT) evidence on the effectiveness of PT interventions for improving gross motor function and balance in children with CP, and to explore which therapies show the most consistent benefits.* ***Methods***: *PubMed, Cochrane Library, Scopus, and PEDro were searched from January 2000 to April 2025 for RCTs involving children aged 1–18 years with CP receiving PT-based interventions targeting gross motor function and/or balance. Eligible outcomes were Gross Motor Function Measure (GMFM-88 Dimensions D and E or GMFM-66) and the Pediatric Balance Scale (PBS). Two reviewers independently performed study selection, data extraction, and risk-of-bias assessment using Cochrane RoB 2.0 and the Jadad scale. Random-effects meta-analyses were conducted using standardized mean differences (SMD) with 95% confidence intervals (CI). The protocol was registered in PROSPERO (CRD420251008653).* ***Results***: *Twenty-eight RCTs including 1084 children met inclusion criteria; 12 contributed to meta-analysis. Pooled analyses showed small-to-moderate benefits of PT interventions over comparison conditions for GMFM-88 Dimension D (10 studies; SMD 0.36, 95% CI 0.15–0.56; $p = 0.0006$; $I^2 = 0\%$), GMFM-88 Dimension E (10 studies; SMD 0.48, 95% CI 0.13–0.83; $p = 0.007$; $I^2 = 61\%$), and PBS (6 studies; SMD 0.43, 95% CI 0.16–0.71; $p = 0.002$; $I^2 = 12\%$). Subgroup analyses suggested comparatively larger effects for task-oriented training, hippotherapy, and virtual reality–assisted programmes, particularly when added to conventional PT. Most trials were of good methodological quality, though blinding of participants and therapists was rarely feasible.* ***Conclusion***: *Current evidence suggests that active, task-oriented and technology-assisted PT interventions, including hippotherapy and virtual reality delivered as adjuncts to conventional therapy, are associated with small-to-moderate improvements in gross motor function and balance in children with CP. However, heterogeneity in protocols, limited stratification by CP subtype and GMFCS level, and scarce long-term follow-up underscore the need for larger, multicenter trials with standardised outcomes and stratified analyses.*

Keywords
cerebral palsy; gross motor function; balance; physical therapy; hippotherapy; virtual reality; randomized controlled trial.

INTRODUCTION
Cerebral palsy (CP) is a lifelong physical disability affecting an estimated 17 million individuals worldwide and is associated with substantial limitations in daily functioning, mobility, and independence, with secondary impacts on quality of life and psychosocial well-being (1, 2). Beyond the individual, CP imposes considerable economic and emotional burden on families, caregivers, health systems, and societies. Global prevalence is estimated at approximately 2–3 cases per 1,000 live births, with a consistently higher prevalence reported in males (SCPE ratio 1.33:1) (3). Prevalence in high-income countries tends to be lower than in low- and middle-income countries, underscoring persistent disparities in prenatal and perinatal care, early diagnosis, and access to rehabilitation services (4).

CP is defined as a group of permanent, but not unchanging, disorders of movement and posture caused by non-progressive disturbances in the developing fetal or infant brain (5, 6). Clinical manifestations typically include spasticity, muscle weakness, postural instability, and impaired selective motor control, often accompanied by sensory deficits and secondary musculoskeletal complications such as deformities and contractures (6, 7). Multiple risk factors contribute to the development of CP across the prenatal, perinatal, and postnatal periods. Prematurity and low birth weight are among the most important determinants (8), while maternal infections, multiple gestation, and other perinatal complications have also been consistently associated with increased risk (9).

The Gross Motor Function Classification System (GMFCS) provides a standardized framework to categorize motor abilities in children with CP across five levels, from I (mild limitations) to V (severe limitations), thereby capturing the wide heterogeneity in functional presentation (10, 11). CP is further classified by motor type into spastic, ataxic, athetoid, and mixed forms, with spastic CP representing roughly 80% of cases (12). Different subtypes and GMFCS levels face distinct challenges related to postural control, balance, and mobility, depending on the location and extent of brain involvement (13). These heterogeneous physical impairments are the primary targets of physical therapy (PT) interventions, which aim to optimize gross motor function, balance, and participation in everyday activities. However, the diversity of presentations and the growing number of therapeutic options make it difficult for clinicians to select the most appropriate, individualized intervention strategy.
Previous systematic reviews have established that PT plays a central role in CP rehabilitation and can yield meaningful gains in motor function and activity (14, 15). Nonetheless, the available evidence remains fragmented and incomplete with respect to comparative effectiveness across the spectrum of CP severity and phenotypes. First, most reviews focus on narrow subsets of interventions such as constraint-induced movement therapy or single-intervention strength training rather than synthesizing the full range of contemporary therapies used in clinical practice. Second, only a minority of studies stratify outcomes by CP subtype or GMFCS level, limiting the ability to match specific interventions to distinct functional profiles. Third, emerging therapies such as dual-task training, virtual reality-based rehabilitation, and robotic-assisted therapy are often evaluated in isolation or in small samples, making it difficult to situate them within an integrated, evidence-based treatment hierarchy (14, 15, 17).
This lack of robust, stratified evidence hampers personalized treatment planning and may contribute to variation in clinical practice, especially in resource-constrained settings where access to specialized equipment and multidisciplinary teams is limited. In many low- and middle-income contexts, clinicians must prioritize interventions that are measurable, achievable with locally available resources, and scalable across different care environments. Identifying which PT approaches provide the greatest improvement in gross motor function and balance for specific CP phenotypes and GMFCS levels and which of these can be delivered using relatively simple, low-cost equipment has the potential to reduce global disparities in CP care.
To address these gaps, the present systematic review and meta-analysis collate and synthesizes evidence from randomized controlled trials published between 2000 and 2025 that evaluated the effects of physical therapy interventions on gross motor function and balance in children with CP. The primary objectives are to evaluate the effectiveness of different PT interventions in improving gross motor function and balance in children with CP, to explore whether specific interventions appear more beneficial for particular severity levels or clinical presentations, and to generate evidence-based recommendations that can guide clinical decision-making and future research priorities.

MATERIALS AND METHODS

The protocol for this systematic review and meta-analysis was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO: CRD420251008653), and all methodological processes adhered to the PRISMA 2020 recommendations for transparent reporting of systematic reviews. A comprehensive search strategy was designed to capture all relevant randomized controlled trials evaluating physical therapy interventions for gross motor function or balance in children with cerebral palsy. Searches were conducted in PubMed, the Cochrane Library, Scopus, and PEDro from January 2000 to April 2025. The search strategy incorporated controlled vocabulary (MeSH terms) and free-text keywords combined with Boolean operators. The full Boolean search string used in PubMed was: (“cerebral palsy” OR “spastic diplegia” OR “spastic quadriplegia”) AND (“physical therapy” OR physiotherapy OR “exercise therapy” OR rehabilitation) AND (“gross motor function” OR GMFM OR mobility) AND (balance OR “Pediatric Balance Scale”) AND (“randomized controlled trial” OR RCT). Equivalent adaptations were applied to the other databases. Reference lists of all included articles and relevant reviews were screened manually to identify additional eligible studies. No protocol amendments were made following registration.
Eligibility criteria were defined a priori using the PICOD framework. The population included children aged 1–18 years with a clinical diagnosis of cerebral palsy of any motor type or GMFCS level. Interventions encompassed any structured physical therapy intervention aimed at improving gross motor function or balance, including task-oriented training, hippotherapy, virtual reality therapy, neurodevelopmental treatment, aquatic therapy, core stability exercises, dynamic surface exercise training, functional progressive resistance exercise, and dual-task game-based training. Comparators consisted of conventional physical therapy, alternative PT approaches, or no intervention. Outcomes of interest included validated measures of gross motor performance (GMFM-66 or GMFM-88 Dimensions D and E) and balance (e.g., Pediatric Balance Scale). Only randomized controlled trials published in English were considered eligible.
Two reviewers independently screened titles, abstracts, and full texts using standardized eligibility forms. Before screening began, both reviewers completed a calibration exercise on a random subset of studies to ensure consistency in applying inclusion criteria. Disagreements at any stage were resolved through discussion, and a third senior reviewer adjudicated unresolved discrepancies. Data were extracted independently by the same reviewers using a piloted extraction sheet capturing study characteristics, participant demographics, intervention protocols, comparator descriptions, and outcome measures. Any inconsistencies in extraction were addressed through consensus.
Risk of bias was assessed independently by two reviewers using the Cochrane Risk of Bias 2.0 (RoB2) tool, which evaluates bias arising from the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Each domain was rated as “low risk,” “some concerns,” or “high risk.” The Jadad Scale was also applied to appraise methodological quality based on adequacy of randomization, blinding, and handling of withdrawals, with scores ≥ 3 indicating high-quality trials. Prior to formal assessment, the reviewers performed a consensus calibration to standardize judgments across RoB2 domains. Any disagreements were resolved by consultation with a third reviewer.
Quantitative synthesis was planned for outcomes reported by at least two trials using comparable measurement tools. Standardized mean differences (SMD) with 95% confidence intervals were selected as the effect measure due to variation in intervention types and study-specific outcome scales. A random-effects model (DerSimonian and Laird) was prespecified to account for anticipated clinical and methodological heterogeneity. Statistical heterogeneity was quantified using the I^2 statistic, with thresholds interpreted as low (0–25%), moderate (26–50%), substantial (51–75%), or considerable (>75%). Sensitivity analyses were planned by sequentially removing studies with high risk of bias. Publication bias was assessed when at least ten studies contributed to a pooled estimate, through visual inspection of funnel plots and Egger’s regression asymmetry test; when fewer than ten trials were available, publication bias was not formally tested due to limited interpretability. The minimal clinically important difference (MCID) for GMFM was considered during interpretation but was not used as an inclusion criterion due to

variability across populations. All analyses were conducted using Review Manager (RevMan) version 5.4.1, following prespecified statistical assumptions and standard meta-analytic procedures.

RESULTS

Study Selection

The database search identified 518 records across PubMed, the Cochrane Library, Scopus, and PEDro. Before screening, 93 records were removed (25 duplicates, 39 records marked as ineligible by automation tools, and 29 records using non–physical therapy interventions). The remaining 425 records were screened by title and abstract, resulting in exclusion of 281 articles that clearly did not meet the eligibility criteria. Full texts were sought for 144 reports; 43 could not be retrieved despite multiple attempts. The remaining 101 articles were assessed for eligibility, of which 73 were excluded (40 due to non-relevant outcomes, 24 because they were not in English, and 9 due to incomplete data). Ultimately, 28 randomized or comparative trials met all inclusion criteria and were included in the qualitative synthesis, and 12 provided sufficiently comparable data for inclusion in the meta-analysis.

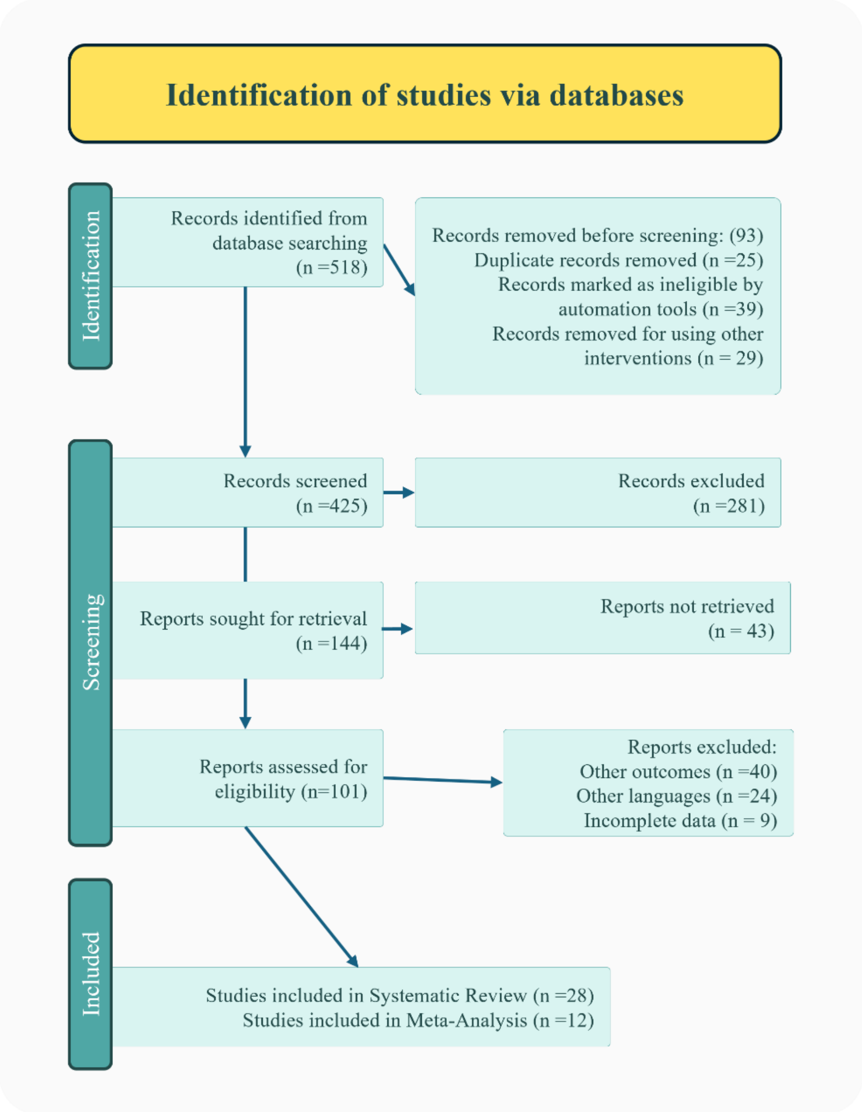

Figure 1 PRISMA 2020 flow diagram of study selection for the systematic review and meta-analysis.

Study Characteristics

The 28 included trials, published between 2001 and 2025, enrolled a total of 1,084 children with cerebral palsy aged 1–18 years. Most samples comprised children with spastic CP (hemiplegic, diplegic, or quadriplegic), with GMFCS levels ranging from I to V where reported. Sample sizes varied from 10 to 92 participants. Across studies, 22 distinct physical therapy intervention were evaluated. These could be grouped into: (i) task-oriented and functional strength–based approaches (e.g. functional therapy, task-oriented strength training, group task-oriented training, functional strength training, task-oriented endurance training); (ii) hippotherapy with varying frequencies; (iii) technology-assisted interventions such as virtual reality, game-based dual-task exercise, and treadmill training with virtual reality; (iv) neurodevelopmental treatment (NDT)–based rehabilitation and NDT combined with routine PT; and (v) adjunctive equipment-based or modality-specific programs, including Biodex balance training, aquatic therapy, antigravity treadmill training, dynamic surface exercise training, functional electrical stimulation, core stabilization, whole-body vibration, and rebound therapy. Conventional physiotherapy, standard rehabilitation therapy, or land-based programs served as comparators in most trials. Gross motor outcomes were commonly measured using GMFM-88 (Dimensions D and E) or GMFM-66, while balance and postural control were assessed using the Pediatric Balance Scale (PBS), Biodex measures, and other validated scales.

Table 1. Characteristics of included studies.

Risk of Bias and Methodological Quality

Cochrane Risk of Bias 2.0 assessments indicated generally strong methodological rigor in several domains. Random sequence generation was judged at low risk in 26 of 28 studies (92.9%), while all trials were rated as low risk for incomplete outcome data and selective reporting (28/28, 100%). Blinding of outcome assessors was adequately described and rated as low risk in 20 studies (71.4%). Allocation concealment was less consistently reported, with 19 trials (67.9%) rated as low risk and the remainder classified as having some concerns or high risk. As expected for physical and behavioral interventions, blinding of participants and personnel (performance bias) was the most problematic domain: 21 studies (75.0%) were rated at high risk because therapists and families could not feasibly be blinded to the treatment allocation, particularly in hippotherapy and equipment-based interventions.

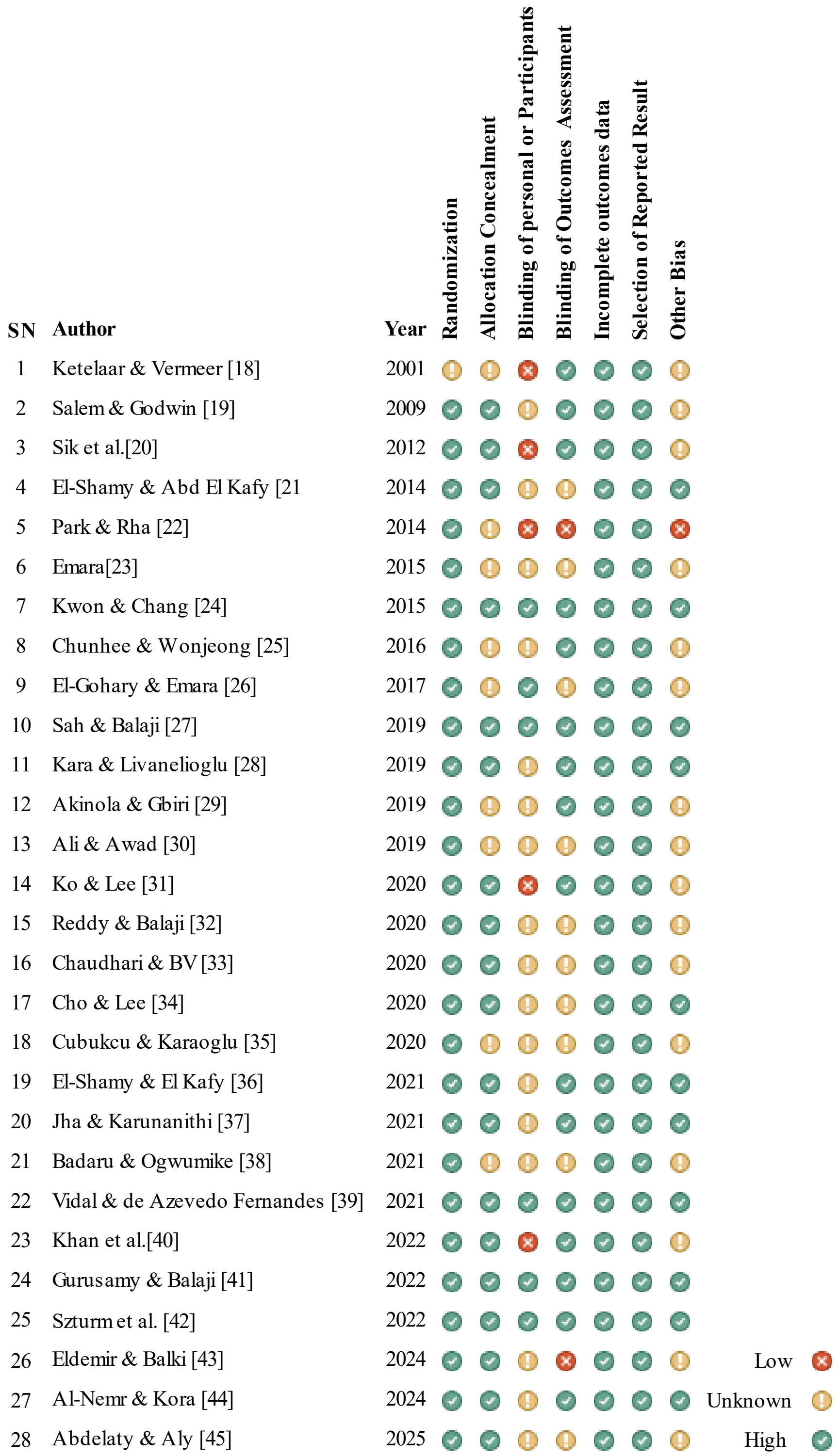

Figure 2. Cochrane Risk of Bias 2.0 summary across included trials.

On the Jadad scale, scores ranged from 2 to 5. The majority of studies (23/28; 82.1%) were classified as high quality with a score ≥3, reflecting adequate reporting of randomization and withdrawals. Only four trials achieved the maximum score of 5 (24, 39, 41, 42), indicating robust randomization procedures and double blinding where feasible. Lower scores were primarily driven by the absence of participant blinding rather than deficiencies in allocation or outcome reporting.

SN	Author	Year	Randomization (0-2)	Blinding (0-2)	Withdrawals/Dropouts (0-1)	Jadad Score (0-5)
1	Ketelaar & Vermeer [18]	2001	1	1	1	3
2	Salem & Godwin [19]	2009	2	1	1	4
3	Sik et al.[20]	2012	2	1	1	4
4	El-Shamy & Abd El Kafy [21	2014	2	0	1	3
5	Park & Rha [22]	2014	1	0	1	2
6	Emara[23]	2015	1	0	1	2
7	Kwon & Chang [24]	2015	2	2	1	5
8	Chunhee & Wonjeong [25]	2016	1	1	1	3
9	El-Gohary & Emara [26]	2017	1	1	1	3
10	Sah & Balaji [27]	2019	2	1	1	4
12	Kara & Livanelioglu [28]	2019	2	1	1	4
13	Akinola & Gbiri [29]	2019	1	0	1	2
14	Ali & Awad [30]	2019	1	0	1	2
11	Ko & Lee [31]	2020	2	1	1	4
15	Reddy & Balaji [32]	2020	2	0	1	3
16	Chaudhari & BV [33]	2020	2	0	1	3
17	Cho & Lee [34]	2020	2	0	1	3
18	Cubukcu & Karaoglu [35]	2020	1	0	1	2
19	El-Shamy & El Kafy [36]	2021	2	1	1	4
20	Jha & Karunanithi [37]	2021	2	0	1	3
21	Badaru & Ogwumike [38]	2021	1	0	1	2
22	Vidal & de Azevedo Fernandes [39]	2021	2	2	1	5
23	Khan et al.[40]	2022	2	1	1	4
24	Gurusamy & Balaji [41]	2022	2	2	1	5
25	Szturm et al. [42]	2022	2	2	1	5
26	Eldemir & Balki [43]	2024	2	1	1	4
27	Al-Nemr & Kora [44]	2024	2	0	1	3
28	Abdelaty & Aly [45]	2025	2	0	1	3

Figure 3. Jadad quality scores included randomized trials.

Meta-analysis of Intervention Effects

Quantitative synthesis was conducted for three primary outcomes: GMFM-88 Dimension D (standing), GMFM-88 Dimension E (walking, running, jumping), and PBS scores.

Ten trials contributed data to the meta-analysis of GMFM-88 Dimension D. The pooled standardized mean difference showed a statistically significant, small-to-moderate improvement in standing function in favour of the intervention groups (SMD 0.36; 95% CI 0.15–0.56; $p = 0.0006$). Statistical heterogeneity was negligible ($I^2 = 0\%$; $Chi^2 = 7.19$, $p = 0.62$), suggesting that, despite differences in specific therapies , the direction and magnitude of benefit on standing ability were consistent across studies.

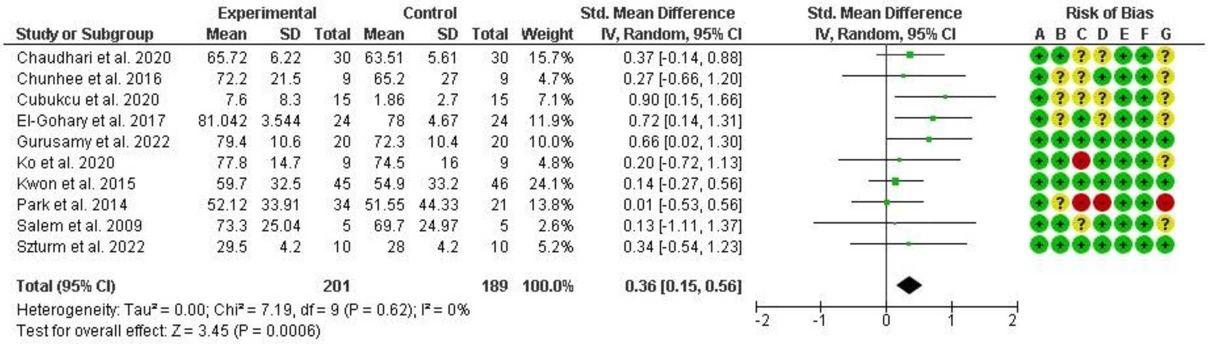

Figure 4. Forest plot of GMFM-88 Dimension D (standing) comparing physical therapy interventions versus controls.

For GMFM-88 Dimension E, ten trials contributed data. The pooled analysis demonstrated a statistically significant, moderate improvement in advanced locomotor skills for participants receiving the experimental interventions compared with controls (SMD 0.48; 95% CI 0.13–0.83; p = 0.007). In contrast to Dimension D, heterogeneity was substantial (I^2 = 61%; Chi^2 = 23.10, p = 0.006). This variability likely reflects differences in intervention type (e.g. task-oriented training, hippotherapy, VR-assisted gait training, functional strength programs), training intensity, and baseline functional status, with some trials focusing on higher-functioning children (GMFCS I–II) and others including broader severity ranges (GMFCS I–IV).

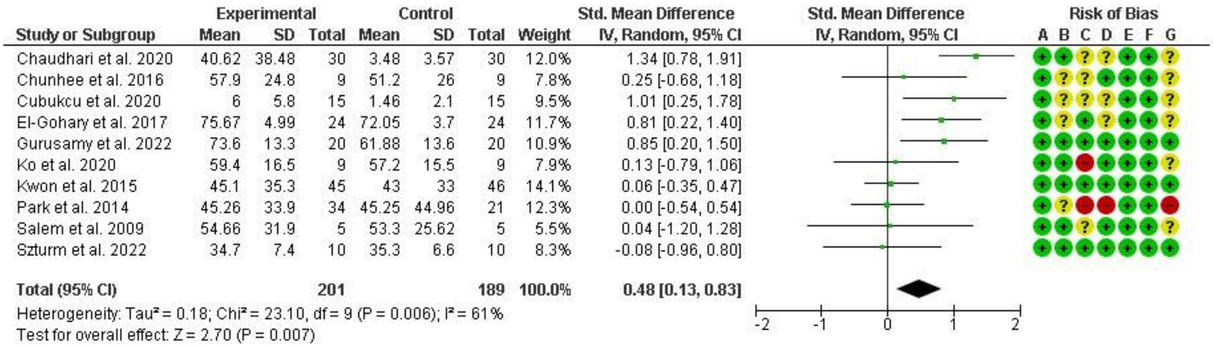

Figure 5. Forest plot of GMFM-88 Dimension E (walking, running, jumping) comparing physical therapy interventions versus controls.

Six trials evaluating balance with the PBS were eligible for pooling. The combined effect demonstrated a statistically significant improvement in balance in favour of the intervention groups (SMD 0.43; 95% CI 0.16–0.71; p = 0.002). Heterogeneity was low (I^2 = 12%; Chi^2 = 5.69, p = 0.34), indicating that different interventions, such as Biodex balance training, dual-task game-based training, VR-assisted intervention, and selected task-oriented programs, had a broadly consistent beneficial effect on PBS scores.

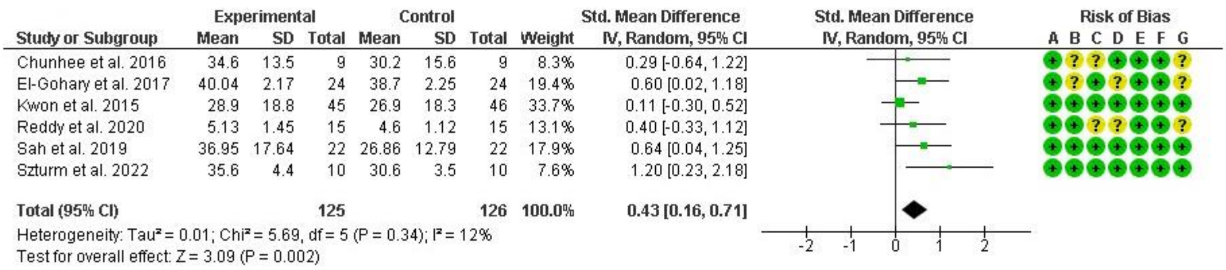

Figure 6. Forest plot of Pediatric Balance Scale (PBS) outcomes comparing physical therapy interventions versus controls.

Subgroup and Sensitivity Analyses

Subgroup analyses by intervention category suggested clinically meaningful patterns. Task-oriented and functional-strength–based approaches (including functional therapy, task-oriented strength training, group task-oriented training, and task-oriented endurance training) consistently favoured the experimental groups, with most trials in this category reporting statistically significant improvements in GMFM dimensions and mobility measures (19, 27, 31, 33, 38, 41). All hippotherapy trials (3 RCTs and 1 frequency-comparison trial) reported significant gains in gross motor function and/or functional performance (20, 22, 24, 39), and in the two trials contributing PBS data, hippotherapy improved balance compared with control or lower-frequency programs. Virtual reality–based and game-based dual-task interventions (25, 37, 42, 43, 45) demonstrated particularly strong and consistent effects on balance, gait, and trunk control when used as adjuncts to conventional PT, aligning with the pooled PBS effect. In contrast, NDT alone showed modest effects on gross motor outcomes, whereas NDT combined with routine PT or task-oriented paradigms yielded more pronounced improvements (27, 35, 40). Sensitivity analyses, restricted to trials with Jadad scores ≥3, did not materially change the direction or statistical significance of pooled effects for GMFM-88 Dimensions D and E or PBS, suggesting that the overall conclusions are robust to exclusion of lower-quality studies. Nonetheless, the unavoidable high risk of performance bias inherent in unblinded rehabilitation trials and the moderate heterogeneity observed for GMFM-88 Dimension E should be considered when interpreting the magnitude of benefit.

Table 1. Characteristics of Included Studies

Author	Year	Country	Type of Study	Sample age	Sample size / CP profile	Experimental intervention (F, I, T)	Control intervention (F, I, T)	Outcome measures	Follow-up	Result
Ketelaar & Vermeer (18)	2001	Netherlands	RCT	2–7 years	N = 55, spastic CP	Functional therapy: F-1/week; I-60 min; T-26 weeks	NDT or Vojta: F-1/week; I-60 min; T-26 weeks	GMFM-88, PEDI	6, 12, 18 months	Functional therapy produced significantly greater improvements in GMFM-88 and PEDI than NDT/Vojta ($p < 0.05$).
Salem & Godwin (19)	2009	USA	RCT	4–12 years	N = 10, CP, GMFCS I–III	Task-oriented strength training: F-2/week; I-NR; T-5 weeks	Conventional PT (CPT): F-2/week; I-NR; T-5 weeks	GMFM-88 (D, E), TUG	Post-treatment only	Task-oriented strength training significantly improved GMFM-88 and TUG compared with CPT ($p = 0.009$).
Sik et al. (20)	2012	Türkiye	RCT	5–15 years	N = 20, spastic CP	Hippotherapy + CPT: CPT F-7/week; I-60 min; T-2 weeks plus hippotherapy F-7/week; I-30–45 min; T-10 weeks	CPT alone: F-7/week; I-60 min; T-12 weeks	GMFM-88, PBS, computerized gait analysis	Post-treatment only	Hippotherapy plus CPT led to significantly greater improvements in GMFM-88, PBS, and gait parameters ($p < 0.05$).
El-Shamy & Abd El Kafy (21)	2014	Egypt	RCT	10–12 years	N = 30, spastic diplegic CP	Traditional PT + Biodex balance training: F-3/week; I-30 min; T-12 weeks	Traditional PT alone: F-3/week; I-30 min; T-12 weeks	PBS, Biodex balance indices	Post-treatment only	Addition of Biodex training significantly improved balance compared with traditional PT ($p < 0.05$).
Park & Rha (22)	2014	Korea	RCT	3–12 years	N = 55, spastic CP, GMFCS I–IV	Hippotherapy: F-1/week; I-45 min; T-8 weeks	Usual PT + OT: F-1/week; I-30 min; T-8 weeks	GMFM-66, GMFM-88, PEDI-FSS	Post-treatment only	Hippotherapy produced significant gains in GMFM and PEDI-FSS versus control ($p < 0.05$).
Emara (23)	2015	Egypt	RCT	6–8 years	N = 30, spastic diplegic CP	Antigravity treadmill gait training + therapeutic exercise: F-3/week; I-60 + 20 min; T-12 weeks	Therapeutic exercise alone: F-3/week; I-60 min; T-12 weeks	Biodex balance measures	Post-treatment only	Antigravity treadmill training significantly improved dynamic balance compared with exercise alone ($p < 0.05$).
Kwon & Chang (24)	2015	Korea	RCT	4–10 years	N = 92, CP, GMFCS I–IV	Hippotherapy: F-2/week; I-30 min; T-8 weeks	Conventional PT program: F-2/week; I-30 min; T-8 weeks	GMFM-88, GMFM-66, PBS	Post-treatment only	Hippotherapy resulted in significantly greater improvements in GMFM and PBS than conventional PT ($p < 0.05$).
Chunhee & Wonjeong (25)	2016	Korea	RCT	4–16 years	N = 18, spastic CP	Treadmill training with virtual reality + CPT: F-3/week; I-30 + 30 min; T-8 weeks	Treadmill training + CPT: F-3/week; I-30 + 30 min; T-8 weeks	GMFM-88, PBS, 10MWT, 2MWT	Post-treatment only	Adding VR to treadmill + CPT produced significantly greater improvements in GMFM-88, PBS, and gait tests ($p < 0.05$).
El-Gohary & Emara (26)	2017	UAE	RCT	5–8 years	N = 48, spastic diplegic CP, MAS 1–1+	Biodex balance training + traditional PT: F-3/week; I-NR; T-12 weeks	Conventional balance training + traditional PT: F-3/week; I-NR; T-12 weeks	GMFM-88 (D, E), PBS, angular knee error	Post-treatment only	Biodex training yielded significantly greater improvements in GMFM-88, PBS, and knee alignment ($p < 0.001$).
Sah & Balaji (27)	2019	India	RCT	7–15 years	N = 44, spastic diplegic CP, GMFCS II–III	Task-oriented activities based on NDT (TOA-NDT): F-6/week; I-60 min; T-6 weeks	Conventional therapy (CPT): F-6/week; I-60 min; T-6 weeks	GMFM-88, PBS, TIS, PAS	Post-treatment only	TOA-NDT significantly improved trunk control, balance, and GMFM-88 compared with CPT ($p < 0.001$).
Kara & Livanelioglu (28)	2019	Türkiye	RCT	7–16 years	N = 30, hemiplegic CP, GMFCS I, MACS I–III	Functional strength training (FST): F-3/week; I-90 min; T-12 weeks	Active comparison (locomotor training, weight bearing, stretching): F-3/week; I-60 min; T-12 weeks	GMFM-88, 1-minute walk test, muscle power, TUG, strength and 1-RM	Post-treatment only	FST produced greater improvements in GMFM-88 and functional performance than the active comparison ($p < 0.05$).
Akinola & Gbiri (29)	2019	Nigeria	RCT	1–12 years	N = 30, spastic CP	Aquatic exercise program: F-2/week; I-100 min; T-10 weeks	Land-based exercise program: F-2/week; I-100 min; T-10 weeks	GMFM-88	Post-treatment only	Aquatic training significantly improved GMFM-88 compared with land-based exercises ($p < 0.05$).
Ali & Awad (30)	2019	Egypt	RCT	5–8 years	N = 60, spastic CP, MAS 1–1+	Regular PT + core stability: F-3/week; I-60 + 30 min; T-12 weeks	Regular PT + whole-body vibration: F-3/week; I-60 + 10 min; T-12 weeks	Biodex balance measures	Post-treatment only	Both interventions improved balance; core stability showed greater gains than whole-body vibration ($p < 0.001$).
Ko & Lee (31)	2020	Korea	RCT	4–7.5 years	N = 18, spastic CP, GMFCS I–III	Group task-oriented training (TOT): F-2/week; I-60 min; T-8 weeks	Traditional rehabilitation therapy: F-2/week; I-60 min; T-8 weeks	GMFM-88, PEDI, BOT-2	Post-treatment only	TOT significantly improved gross and fine motor function and ADL compared with traditional therapy ($p < 0.05$).
Reddy & Balaji (32)	2020	India	RCT	5–12 years	N = 30, spastic quadriplegic CP	Dynamic surface exercise training (DSET): F-4/week; I-60 min; T-6 weeks	Standard physiotherapy training (SPT): F-4/week; I-60 min; T-6 weeks	GMFM-88, PBS	Post-treatment only	DSET significantly improved trunk control and GMFM-88 compared with SPT ($p \leq 0.05$).
Chaudhari & BV (33)	2020	India	Comparative study	8–13 years	N = 60, spastic diplegic CP, GMFCS I–III	Task-oriented training (TOT): F-5/week; I-NR; T-5 weeks	Functional progressive resistance exercise (FPRE): F-5/week; I-NR; T-5 weeks	GMFM-88 (D, E), Mobility Questionnaire	Post-treatment only	Both groups improved; TOT yielded greater gains in selected GMFM-88 and mobility outcomes ($p < 0.05$).
Cho & Lee (34)	2020	Korea	RCT	6–13 years	N = 25, spastic CP, GMFCS I–III	FPRE: F-3/week; I-30 min; T-6 weeks	Control physiotherapy: F-3/week; I-30 min; T-6 weeks	Muscle tone, functional reach test, GMFM-88	Post-treatment only	FPRE reduced muscle tone and improved dynamic balance and GMFM-88 versus control ($p < 0.05$).

Author	Year	Country	Type of Study	Sample age	Sample size / CP profile	Experimental intervention (F, I, T)	Control intervention (F, I, T)	Outcome measures	Follow-up	Result
Cubukcu & Karaoglu (35)	2020	Türkiye	RCT	2–5 years	N = 30, spastic CP	NDT-based rehabilitation: F-3/week; I-60 min; T-12 weeks	Conventional home program: F-NR; I-NR; T-12 weeks	GMFM-88	Post-treatment only	NDT-based rehabilitation significantly improved GMFM-88 compared with home program ($p < 0.05$).
El-Shamy & El Kafy (36)	2021	Saudi Arabia	RCT	8–12 years	N = 30, hemiplegic CP, GMFCS I–II	Functional electrical stimulation + PT: F-3/week; I-60 min; T-12 weeks	Traditional PT: F-3/week; I-120 min; T-12 weeks	Biodex balance measures	Post-treatment only	FES plus PT significantly improved postural control compared with traditional PT ($p < 0.001$).
Jha & Karunanithi (37)	2021	India	RCT	6–8 years	N = 38, bilateral spastic CP, GMFCS II–III, MACS I–III	Virtual reality games + physiotherapy: F-4/week; I-60 min; T-6 weeks	Physiotherapy alone: F-4/week; I-60 min; T-6 weeks	PBS, Kids-Mini-BESTest, GMFM-88, WeeFIM	Post-treatment only	VR + PT significantly improved balance, gross motor performance and daily function compared with PT alone ($p < 0.05$).
Badaru & Ogwumike (38)	2021	Nigeria	RCT	4–12 years	N = 39, CP	Task-oriented exercise training (TOET): F-2/week; I-40 min; T-12 weeks	CPT: F-2/week; I-40 min; T-12 weeks	MobQues-28	Post-treatment only	TOET led to significantly better functional performance scores than CPT ($p < 0.05$).
Vidal & de Azevedo Fernandes (39)	2021	Brazil	RCT	2–5.11 years	N = 19, CP	Hippotherapy once weekly: F-1/week; I-30 min; T-16 weeks	Hippotherapy twice weekly: F-2/week; I-30 min; T-16 weeks	GMFM-66, PEDI	Post-treatment only	Twice-weekly hippotherapy produced greater gains than once-weekly sessions ($p < 0.05$).
Khan et al. (40)	2022	Pakistan	RCT	2–6 years	N = 66, spastic CP	NDT + routine PT: F-3/week; I-NR; T-12 weeks	Routine PT (active and passive ROM + stretching): F-3/week; I-NR; T-12 weeks	GMFM-88, PPAS	12 weeks	NDT + routine PT significantly improved GMFM-88 and postural control compared with routine PT alone ($p \leq 0.05$).
Gurusamy & Balaji (41)	2022	India	RCT	5–14 years	N = 40, spastic diplegic CP, GMFCS I–III	Functional strength training (FST): F-3/week; I-45–60 min; T-6 weeks	CPT: F-3/week; I-45–60 min; T-6 weeks	GMFM-88 (D, E), goal total score	2 months	FST produced significantly greater improvements in GMFM-88 and goal attainment than CPT ($p < 0.003$).
Szturm et al. (42)	2022	Canada	RCT	4–8 years	N = 20, CP, GMFCS I–III, MAS 0–1+	Game-based dual-task balance training: F-3/week; I-45 min; T-12 weeks	CPT balance program: F-3/week; I-45 min; T-12 weeks	PBS, GMFM-88, computerized standing balance measures	Post-treatment only	Dual-task game-based training significantly improved PBS, GMFM-88, and balance metrics compared with CPT ($p < 0.05$).
Eldemir & Balki (43)	2024	Türkiye	RCT	5–15 years	N = 35, mild CP, GMFCS I–II	Xbox Kinect virtual reality + conventional PT: F-2/week; I-60 min (30 min VR + 30 min PT); T-6 weeks	Conventional PT: F-2/week; I-30 min; T-6 weeks	Balance (FFRT, FSRT), gait (10MWT), trunk control (TIS), MAS	Post-treatment only	VR + PT significantly improved balance, gait, and trunk control and reduced spasticity versus PT alone ($p < 0.05$).
Al-Nemr & Kora (44)	2024	Egypt	RCT	5–8 years	N = 52, spastic hemiplegic CP, MAS +1–2, GMFCS II–III	Core stabilization exercises: F-3/week; I-90 min; T-12 weeks	Rebound therapy: F-3/week; I-90 min; T-12 weeks	Biodex balance measures, 6MWT	Post-treatment only	Core stabilization produced greater improvements in balance and walking endurance than rebound therapy ($p < 0.0001$).
Abdelaty & Aly (45)	2025	Egypt	RCT	6–8 years	N = 30, spastic diplegic CP	Traditional PT + VR training: F-3/week; I-45–60 min + 20 min; T-12 weeks	Traditional PT: F-3/week; I-45–60 min; T-12 weeks	SATCO, Biodex balance measures	Post-treatment only	PT combined with VR significantly improved trunk control and balance compared with PT alone ($p = 0.001$).

DISCUSSION

This systematic review and meta-analysis synthesized evidence from 28 trials to evaluate the effectiveness of a broad range of physical therapy interventions on gross motor function and balance in children with cerebral palsy. Overall, the findings indicate that active, functional, and technology-assisted programmes are associated with statistically significant improvements in standing, advanced locomotor skills, and balance, with pooled effect sizes in the small-to-moderate range for GMFM-88 Dimensions D and E and the Pediatric Balance Scale. These magnitudes suggest that, while the average gains are not transformative, they are clinically relevant when considered against the chronic nature of CP, the limited spontaneous recovery expected, and the cumulative impact of repeated therapeutic cycles across childhood.

Task-oriented approaches emerged as a consistently beneficial category across the included trials. Interventions that required children to practise real-life, goal-directed activities such as task-oriented strength training, group task-oriented training, and task-oriented exercise programmes demonstrated superior improvements in mobility and gross motor function compared with conventional physiotherapy in several studies (19,27,31,38). The comparative trial by Chaudhari and colleagues (33) further suggested that, although both functional progressive resistance exercise and task-oriented training improve functional outcomes, task-focused practice may confer additional benefits for certain mobility domains. Collectively, these findings support the current shift toward activity-based, participation-focused rehabilitation models in paediatric neurorehabilitation.

Hippotherapy also showed a consistent pattern of benefit. Across studies, programmes that used the horse's multidimensional movement to stimulate trunk and pelvic musculature produced significant gains in gross motor function, balance, and functional performance compared with conventional therapy, lower-frequency hippotherapy, or usual care (20,22,24,39). Although these interventions may be resource-intensive and less accessible in low-resource settings, the relatively robust and homogeneous improvements in GMFM scores suggest that hippotherapy can be a valuable option for appropriately selected children, particularly those with spastic presentations and moderate functional limitations.

Technology-assisted interventions, especially virtual reality–based and game-based dual-task training, provided some of the most promising results for balance, trunk control, and gait. Trials incorporating Wii-based or Kinect-based virtual reality into conventional physiotherapy reported significant additional improvements in balance, walking speed, and trunk control compared with physiotherapy alone (25,37,42,43,45). These interventions leverage multisensory, repetitive, and engaging feedback that may enhance motor learning and adherence, particularly in school-aged children. Similarly, treadmill training combined with virtual reality was associated with superior gains in gait and balance relative to treadmill training without virtual elements (25). The pattern of results suggests that virtual reality is most effective when used as an adjunct to, rather than a replacement for conventional therapy.

The evidence for neurodevelopmental treatment is more mixed. Trials examining NDT alone reported modest improvements in gross motor function, whereas studies in which NDT principles were integrated into task-oriented or routine physiotherapy programmes demonstrated more substantial gains (27,35,40). This implies that NDT may contribute most effectively when embedded within structured, goal-directed practice rather than as a stand-alone paradigm. Equipment-based modalities such as Biodex balance training, antigravity treadmill training, dynamic surface exercise training, and core stabilization programmes also produced significant improvements in balance and postural control, particularly when layered onto conventional therapy (21,23,26,32,36,41,44). In contrast, whole-body vibration and rebound therapy, while beneficial, tended to yield smaller gains than targeted core stabilization or task-oriented strengthening (30,44).

Despite these encouraging findings, several limitations temper the certainty and generalisability of the evidence. First, clinical and methodological heterogeneity was substantial for some outcomes, particularly GMFM-88 Dimension E, where variability in intervention type, training intensity, treatment duration, and baseline GMFCS levels likely contributed to the observed I^2 of 61%. Second, most trials enrolled relatively small samples, were single-center, and frequently pooled children with different CP subtypes and functional levels, limiting the ability to identify which interventions are optimally matched to specific GMFCS strata or motor phenotypes. Third, long-term follow-up was rare; apart from a few studies with follow-up beyond the immediate post-treatment period, the durability of gains remains uncertain, and it is unclear whether improvements translate into sustained participation and reduced secondary complications over time.

Methodological considerations also affect the certainty of the findings. While random sequence generation, attrition, and selective reporting were generally well controlled, performance bias was almost universally high because blinding of therapists and participants was not feasible in most physical interventions. Allocation concealment and assessor blinding were inconsistently reported, and only a minority of studies achieved the highest Jadad scores (24,39,41,42). Taken together, the body of evidence would likely be rated as moderate certainty for short-term improvements in GMFM-88 and PBS with task-oriented, hippotherapy, and VR-based programmes, and low-to-moderate certainty for other intervention categories, particularly where data are sparse or heterogeneous.

From a clinical perspective, the small-to-moderate pooled effect sizes observed for GMFM and PBS should be interpreted in the context of individual goals, resource availability, and feasibility. For many children with CP, even modest gains in standing balance or walking endurance can translate into meaningful improvements in independence, caregiver burden, and participation in school or community activities. Interventions that combine task-oriented practice with engaging technologies or multisensory modalities appear especially promising, provided they are delivered with sufficient intensity and within a structured, family-centered framework. Future research should prioritise adequately powered, multicentre trials that use harmonised outcome measures, stratify participants by CP subtype and GMFCS level, incorporate longer-term follow-up, and report core outcomes relevant to function and participation. Comparative-effectiveness designs that directly contrast scalable, low-cost options (e.g. home-based task training, simplified VR, group classes) with more resource-intensive modalities (e.g. hippotherapy, specialised equipment) are particularly needed to inform practice in diverse health-care settings.

CONCLUSION

This systematic review and meta-analysis indicate that targeted physical therapy interventions including task-oriented training, hippotherapy, and virtual reality assisted programmes are associated with small-to-moderate but clinically meaningful improvements in gross motor function and functional balance among children with cerebral palsy. Although these findings are supported by generally good methodological quality and consistent direction of effect across trials, they are constrained by performance bias, limited stratification by CP subtype and GMFCS level, and scarce long-term follow-up. Integrating evidence-based, active, and engaging interventions into routine rehabilitation practice, while simultaneously conducting larger, stratified, and longer-duration trials, is likely to enhance functional independence and participation for children living with cerebral palsy.

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