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Systematic Review and Meta-Analysis

The Impact of Physical Exercise Interventions on Gait Performance in Individuals with Down Syndrome: A Systematic Review and Meta-Analysis

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Purpose: The objective of this study was to assess the impact of structured physical exercise on gait performance among people with Down syndrome (DS), providing evidence-based exercise recommendations.
Methods: A comprehensive search of EBSCO, PubMed, Cochrane Library, Embase, Web of Science Core Collection, and Scopus was conducted up to April 2024 and updated in April 2025. Randomized controlled trials (RCTs) and quasi-RCTs comparing structured physical exercise interventions with non-exercise or usual care controls were included. Meta-analyses were performed on gait-related outcomes, including the 8-foot Up and Go Test (8UG) and the 6-minute Walking Distance Test (6MWT). A descriptive synthesis was conducted for outcomes where a meta-analysis was not feasible due to substantial heterogeneity or insufficiently comparable data across studies.
Results: A total of eight studies (seven RCTs and one quasi-RCT) involving 202 participants were included. Physical exercise interventions significantly improved 6MWT (mean difference (MD) = 43.19; 95% confidence interval (CI): 19.50 to 66.88; I^2 = 0%; P = .0004) and 8UG (MD = .76; 95% CI: .27 to 1.25; I^2 = 0%; P = .002). The descriptive analysis indicated that physical exercise may improve walking speed, the Timed Up and Go Test (TUG), spatial parameters, and joint kinematics among individuals with DS.
Conclusion: Preliminary evidence shows that structured physical exercise may be associated with improvements in gait performance in individuals with DS; however, the overall certainty of the evidence remains low due to the small sample sizes and methodological limitations. Future high-quality studies are required to validate these findings, compare structured exercise interventions with active control programs matched for exercise volume, and identify the most effective exercise modes, intensities, and individualized strategies for gait rehabilitation in this population.
Systematic review registration: INPLASY202540108

Keywords: Down syndrome, gait performance, functional mobility, physical exercise, meta-analysis

Introduction

Down syndrome (DS), or trisomy 21 (OMIM #190685), is the most common chromosomal abnormality associated with intellectual disability and neuromotor impairments, with a global prevalence of approximately 1 in 800 live births [1,2]. The condition results from a full or partial triplication of chromosome 21 and is associated with a broad clinical phenotype [2]. Core characteristics include generalised hypotonia, atlantoaxial instability, cognitive impairment, and congenital heart defects [2,3]. People with DS are also at an increased risk of developing multisystem comorbidities, including respiratory infections, gastrointestinal malformations, thyroid dysfunction, osteoporosis, epilepsy, Alzheimer's disease, and both metabolic and autoimmune disorders [4-9]. Among these manifestations, neuromotor impairments are particularly evident in delayed motor development, characterised by impaired postural control and atypical gait patterns, which are hallmark features of the syndrome [10].
To accurately interpret the gait function of individuals with DS, it is essential to compare their gait characteristics with normative datasets from healthy individuals. A study developed a reference database of spatio-temporal and kinetic gait parameters in healthy young Tunisian adults [11]. This database offers critical benchmarks for identifying pathological deviations and informing clinical assessments. Compared with healthy controls, individuals with DS typically exhibit gait abnormalities such as reduced walking velocity, shortened step and stride lengths, increased stride width, and exaggerated hip flexion [10,12]. Additional abnormalities such as hip external rotation, excessive knee flexion and valgus, and tibial external rotation are also prevalent [13,14]. Gait dysfunction in DS is multifactorial. Hypotonia, ligamentous laxity, and impaired postural control directly contribute to biomechanical inefficiency [2,15]. In addition, structural and functional alterations in the central nervous system (CNS), particularly cerebellar hypoplasia and deficits in sensorimotor integration may further impair gait coordination and timing [16,17]. Gait ability is increasingly recognised as a developmental marker closely linked to cognition, social interaction, and motor skills [18]. Gait impairments associated with DS increase the metabolic cost of walking, contribute to physical inactivity, and elevate

dependence on activities of daily living, collectively reducing quality of life [19-21]. Notably, these impairments often persist into childhood and adulthood [22], underscoring the importance of targeted rehabilitation approaches such as physical exercise, and physiotherapy to optimise gait function, enhance self-care capabilities, and support long-term health outcomes in individuals with DS [23,24].

In this context, physical exercise refers to a specific type of physical activity that is intentional, structured, and repetitive [25]. It aims to enhance or maintain physical fitness and represents a fundamental component of comprehensive intervention strategies [23-25]. Physical exercise benefits for people with DS are well documented. Studies have demonstrated that physical exercise such as swimming programs, stretching and dance can effectively improve balance, aerobic capacity and postural control in DS patients [26-28]. Although current evidence has established that physical exercise interventions can improve motor function in individuals with DS, most studies focus on postural control, muscle strength and balance [29-31]. To our knowledge, systematic reviews examining the impact of exercise programs on gait ability in people with DS remain limited. Therefore, this study aims to assess the impact of structured physical exercise programs on gait performance in people with DS. By focusing specifically on gait-related parameters, this study may provide evidence-based guidance for healthcare professionals when implementing physical exercise for individuals with DS.

Methods

This meta-analysis protocol was retrospectively registered with the International Platform for Registered Systematic Reviews and Meta-Analysis Protocols (INPLASY) (registration number: INPLASY202540108) in April 2025. This review was conducted in compliance with the updated 2020 guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) (Supplementary Table 1) [32].

Search Strategy

A literature search was conducted in EBSCO, PubMed, Scopus, Embase, the Web of Science Core Collection, and the Cochrane Central Register of Controlled Trials. The initial search was completed in April 2024 and was subsequently updated in April 2025. The search strategy combined Medical Subject Headings (MeSH) and relevant free-text terms related to "Down syndrome", "physical exercise", and "gait performance" (Supplementary Table 2). In addition, reference lists of eligible studies and relevant systematic reviews were manually screened to retrieve any further studies meeting the inclusion criteria.

Study Eligibility

Two reviewers independently assessed the eligibility of the selected studies. The inclusion criteria were established based on the PICOS framework (Population, Intervention, Comparator, Outcome, Study Design) in Table 1.

Study Selection

The study selection procedure was carried out in three stages. First, two reviewers independently searched the databases and identified potential relevant studies. Second, titles and abstracts were screened after duplicate removal. Third, the full texts of the remaining articles were reviewed to confirm eligibility for final inclusion. All records were imported into Rayyan (https://rayyan.qcri.org/welcome) [33]. The independent screening was performed by both reviewers, and any disagreements were resolved through discussion based on predefined inclusion and exclusion criteria. If consensus could not be reached, a senior reviewer was consulted for adjudication. Additionally, reference lists of previous systematic or narrative reviews related to structured physical exercise interventions in individuals with DS were manually screened to identify any potentially missed studies.

Data Collection and Extraction

An EndNote library (Clarivate Analytics, New York, NY, USA) was used for data management. (1) study details (first author's last name and year of publication); (2) study design (RCT) or quasi-RCT; (3) country of origin; (4) participant characteristics, including age (reported as mean ± standard deviation or range), sample size, and percentage of male/female participants, body mass index (BMI); (5) intervention characteristics described according to the frequency, intensity, time, and type (FITT) principle, including the specific type of physical exercise; and (6) outcome measures, including gait-related parameters such as kinematic, kinetic, or functional assessments of gait performance were extracted from the included research. Although gait parameters are widely used and generally reliable in both clinical and research settings, measurement outcomes may be affected by variability in protocols, assessor training, and participant compliance. A previous study emphasized that even biomechanically grounded assessments require careful methodological consideration to ensure accuracy and interpretability [34]. Data extraction and verification were independently performed by two independent reviewers.

Quality Assessment and Risk of Bias

Risk of bias was evaluated by two reviewers. Discrepancies were resolved through consensus discussions, and when necessary, a third reviewer was consulted to reach agreement. The included studies (RCTs) were assessed using the Physiotherapy Evidence Database (PEDro) scale [35]. The Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was employed to assess the included quasi-RCTs [36].

Statistical Analysis

Meta-analyses were conducted using Review Manager (RevMan, version 5.3) and Stata software (version 12.0; StataCorp, College Station, TX, USA). Studies reporting comparable outcomes were synthesized when at least three eligible studies were available, consistent with methodological guidance recommending a minimum of three studies to permit basic heterogeneity estimation and ensure a meaningful interpretation of forest plots [37]. Adjusted mean differences (MDs) and standard deviations (SDs) were extracted, and effect sizes were reported with 95% confidence intervals (CIs). Standardized mean differences (SMDs) were calculated for the outcomes evaluated by different methods. Heterogeneity across studies was assessed using Cochran's Q test and the I^2 statistic. In accordance with the Cochrane Handbook for Systematic Reviews of Interventions, I^2 values were interpreted contextually, considering the magnitude and direction of the effects, as well as the extent of clinical and methodological heterogeneity [37]. A random-effect model was applied when heterogeneity was substantial ($P < .10$ and $I^2 > 50\%$); otherwise, a fixed-effect model was used. Sensitivity analyses were conducted to evaluate the robustness of the results. Subgroup analyses were performed, when feasible, to explore potential sources of heterogeneity. When a meta-analysis was not feasible, findings from high-quality studies were summarized narratively. Results were presented in tables, forest plots, and supplemented by a narrative interpretation.

Publication Bias

Publication bias was assessed by analysing funnel plot asymmetry using Egger's linear regression test [38]. If significant publication bias was identified, Duval and Tweedie's trim and fill approach was utilized to modify the pooled estimates accordingly [39].

Table 1. Inclusion and exclusion criteria

Category	Inclusion Criteria	Exclusion Criteria
Population	Participants with a confirmed clinical diagnosis of Down syndrome.	Studies involving participants without a confirmed diagnosis of Down syndrome, or with mixed or unspecified developmental conditions.
Intervention	Structured physical exercise interventions of any type (e.g., aerobic, resistance training), conducted at least twice per week for a minimum duration of eight weeks.	Interventions not involving physical exercise (e.g., pharmacological, behavioral-only programs) or those conducted fewer than twice per week or lasting fewer than eight weeks.
Comparator	A control group receiving no structured exercise intervention (e.g., standard care, usual activities, or no intervention).	Studies without a control group or with an active comparator involving structured physical activity.
Outcome	At least one gait-related outcome, including kinematic (e.g., step length, walking speed), kinetic, or functional assessments (e.g., Timed Up and Go Test, 6-minute Walking Distance Test).	Studies lacking gait-related outcomes or those without baseline or follow-up measurements.
Study Design	Randomized controlled trials (RCT) or quasi-RCT.	Non-controlled studies, case reports, cross-sectional designs, or qualitative research.
Language	Full-text articles published in peer-reviewed English-language journals.	Non-English publications

Grading of Evidence

The overall quality of evidence was evaluated by two reviewers using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach [40].

Results

Search Results

In the preliminary search, a total of 1,221 relevant records were identified. These records included 178 from Scopus, 122 from Web of Science Core Collection, 507 from Cochrane Library, 249 from Ebsco, 52 from Embase, and 113 from PubMed. Given the overlapping coverage among databases, 635 duplicates were removed by Rayyan, 85 studies were excluded after title and abstract screening, and 193 after full-text review. 8 studies met the eligibility criteria and were included in the study (Figure 1) [41-48].

Description of Included Studies

Among the eight articles included in this study, seven were RCTs and one was quasi-RCT, with publication dates ranging from 2011 to 2023. The overall number of participants included in the studies was 202 (experimental group: n = 110, control group: n = 92), with ages ranging from 11 to 52 years. One study did not report the gender difference between groups. The included studies were conducted across various geographical regions, including Europe (Poland, Portugal, and France; n =

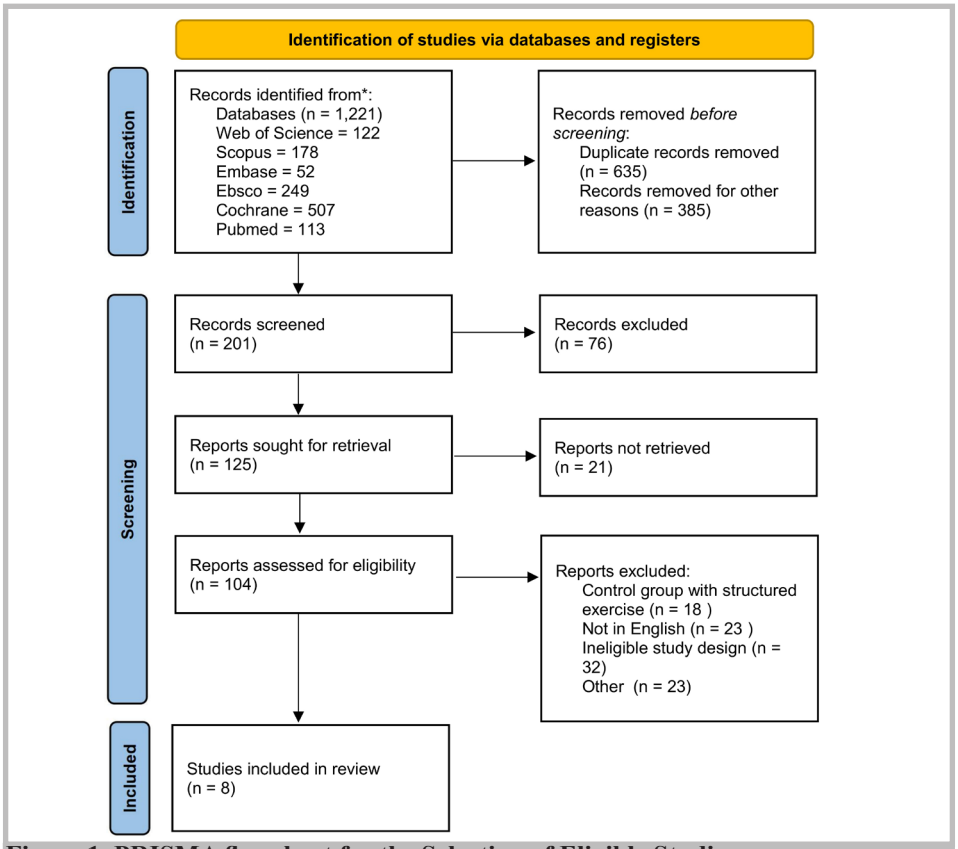

Figure 1. PRISMA flowchart for the Selection of Eligible Studies.

3), Africa (South Africa; n = 2), Asia (Turkey; n = 1), North America (United States; n = 1), and Oceania (Australia; n = 1). Exercise interventions included resistance training, Nordic walking, swimming, Wii-based exercise games, and other physical activities. Control groups typically received the usual care or continued with their routine daily activities. Although one study included weekly social activities, none of the control groups received structured physical exercise. Intervention durations ranged from 8 to 12 weeks, with training frequencies of 2 to 3 sessions per week. Each training session typically lasts between 30 and 60 minutes (Table 2).

Methodological Quality and Risk of Bias

The methodological quality of the included RCTs, as assessed by PEDro, ranged from moderate to good (scores 6-8). All studies employed random allocation, and most demonstrated adequate follow-up and provided between-group comparisons with variability estimates. However, the absence of blinding for participants and therapists emerged as a consistent methodological limitation, which is an inherent constraint in physical exercise interventions that may compromise internal validity despite otherwise sound design features (Supplementary Table 3 and 4).

Meta-analysis

8-foot Up and Go Test

Two articles with three studies evaluated 8UG in individuals with DS, involving 84 people. As the evaluation methods were consistent across studies, MD was used as the effect size for the pooled analysis. Compared with the control group, structured physical exercise interventions can significantly improve 8UG in individuals with DS (MD = .76; 95% CI = .27 to 1.25; P = .002; I^2 = 0%) (Figure 2A).

6-minute Walking Distance Test

Five articles comprising six studies evaluated the 6MWT of individuals with DS, involving a total of 139 participants. As the evaluation methods were consistent across studies, the MD was used as an effect size for a pooled analysis. Compared with the control group, structured physical exercise interventions can effectively improve the 6MWT of individuals with DS (MD = 43.19; 95% CI = 19.50 to 66.88; P = .0004; I^2 = 0%) (Figure 2B).

Descriptive Analysis

Timed Up and Go Test

Three of the included RCTs investigated the impact of exercise programs on TUG in people with DS. The studies varied in participant age, one included children (mean age ≈ 12 years), while the other two focused on adults. Given this clinical heterogeneity and the limited number of eligible studies,

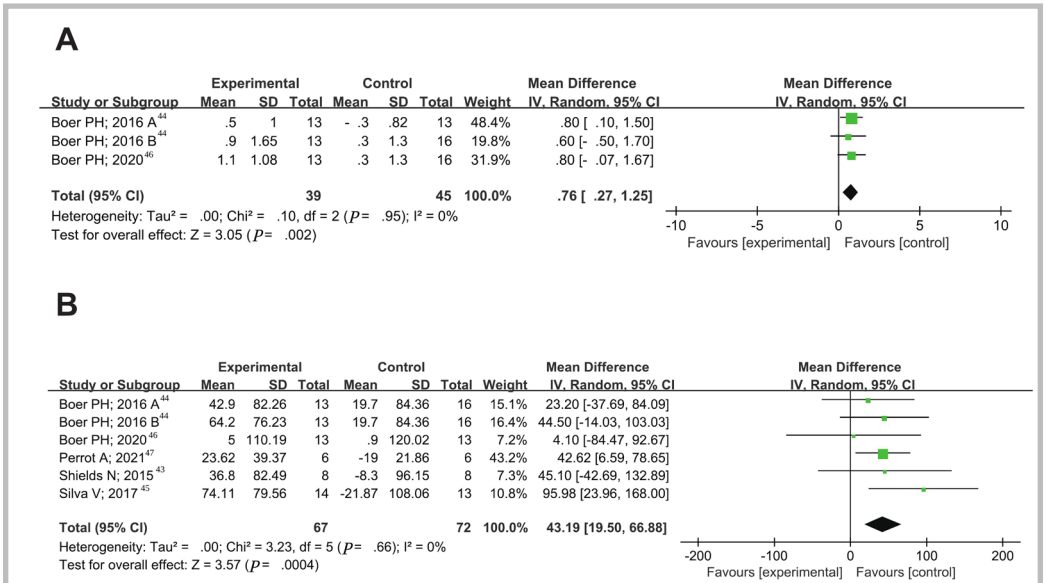

Figure 2. Forest plot of a meta-analysis on the effects of physical exercise interventions on (A) 8UG and (B) 6MWT

8UG: 8-foot Up and Go Test; 6MWT: 6-minute Walking Distance Test. Each plot includes 95% confidence intervals (CIs), IV: inverse variance method, SD: Standard Deviation, Std: Standardized.

pooling the TUG data in a meta-analysis was methodologically inappropriate and could have introduced bias. In addition, the small number of studies precluded meaningful subgroup or sensitivity analyses. Therefore, a descriptive synthesis was conducted. Perrot et al. examined the effects of a 12-week Wii-based exergaming program in adults and reported significant improvements in TUG compared to controls (P < .01, Cohen's d = 2.23). Silva et al. conducted an 8-week exergaming program in adults and found significantly greater improvements in TUG in the exergaming program group compared to the no-exercise group (P = .049). Büyükçelik et al. evaluated an 8-week balance training in children and observed significant improvements in TUG performance across three conditions (single, motor dual-task, and cognitive dual-task) within the intervention group and relative to controls (P < .05).

Walking Speed

Three studies reported outcomes related to walking speed. One of them employed a quasi-RCT, while the others were RCTs. Given this variation in study design and the small number of studies, pooling the results into a meta-analysis was considered methodologically inappropriate and could have introduced bias. Moreover, the small number of studies precluded meaningful subgroup or sensitivity analyses. Therefore, the results were synthesized descriptively. Two studies reported slight improvements in walking speed following structured exercise interventions; however, neither demonstrated statistically significant between-group differences. In contrast, Skiba et al. observed a significant improvement in walking speed after a 10-week Nordic Walking program, with a significant group × time interaction (F = 5.35, P = .035).

Spatial Parameters and Joint Kinematics

As only one study reported spatial parameters and joint kinematics, a descriptive analysis was conducted. The included study reported significant improvements in step length and

Table 2. Characteristics of included studies (N = 8).

First author (year)	Study design	Country	Diagnosis	Sample size	Gender (F/M)	Age (years)	Height (cm)	BM (kg)	BMI	EG	CG	Outcomes
Cowley PM (2011) [41]	Quasi-RCT	USA	DS	EG: 19 CG: 11	EG: 9/10; CG: 8/3	EG: 29 ± 9; CG: 27 ± 7	EG: 152.8 ± 8.3; CG: 154.3 ± 4.4	EG: 79.1 ± 13.3; CG: 74.1 ± 15.8	EG: 33.8 ± 6.1; CG: 30.8 ± 6.8	Progressive resistance training; 2 sessions/week; 10 weeks.	Maintain daily routine, without structured exercise.	Walking speed
Skiba A (2011) [42]	RCT	Poland	DS	EG: 11 CG: 11	1 1 / 1 1 (combined; EG and CG not reported).	EG: 30.3 ± 2.8; CG: 32.0 ± 5.2	EG: 156 ± 6.9; CG: 152 ± 10.2	EG: NI CG: NI	EG: NI CG: NI	Nordic walking; 60 min/session; 3 sessions/week; 10 weeks.	Maintain daily routine, without structured exercise.	Walking speed, Step length, cycle length, ankle/knee/pelvis/shoulder kinematics
Shields N (2015) [43]	RCT	Australia	DS	EG: 8; CG: 8.	EG: 3/5; CG: 5/3.	EG: 21.6 ± 3.4; CG: 21.2 ± 3.2	EG: 149.1 ± 8.8; CG: 154.1 ± 8.8	EG: 71 ± 11; CG: 67 ± 10	EG: 32.2 ± 6.3; CG: 28.1 ± 3.0	Walking program; 60 min/session; 3 sessions/week; 8 weeks.	Weekly 90-min social activity, without structured exercise.	6MWT Walking speed
Boer P.H. (2016) [44]	RCT	South Africa	DS	EG: 13; EG: 13; CG: 16.	EG1: 5/8; EG2: 6/7; CG: 6/10	EG1: 30.0 ± 7.4; EG2: 34.2 ± 9.2; CG: 36.6 ± 8.4	EG1: 156.8 ± 7.5; EG2: 151.3 ± 6.6; CG: 155.5 ± 7.8	EG1: 69.4 ± 8.3; EG2: 69.2 ± 14.6; CG: 74.1 ± 8.4	EG1: 28.5 ± 4.0; EG2: 30.2 ± 6.3; CG: 30.9 ± 4.2	Interval training; 30-35 min/session; 3 sessions/week; 12 weeks. Continuous aerobic training; 30-35 min/session; 3 sessions/week; 12 weeks.	Maintain daily routine, without structured exercise.	8UG 6MWT
Silva V (2017) [45]	RCT	Portugal	DS	EG: 14; CG: 13.	NI	EG: 30.0 ± 7.0; CG: 29.5 ± 6.5	EG: NI CG: NI	EG: 71.43 ± 14.80; CG: 69.65 ± 17.41	EG: 32.42 ± 6.24; CG: 31.89 ± 6.80	Wii-based exercise program; 60 min/session; 3 sessions/week; 8 weeks.	Maintain daily routine, without structured exercise.	TUG 6MWT
Boer P.H. (2020) [46]	RCT	South Africa	DS	EG: 13; CG: 13.	EG: 7/6; CG: 6/7	EG: 34.2 ± 5.0; CG: 30.3 ± 7.2	EG: NI CG: NI	EG: 79.1 ± 21.4; CG: 81.6 ± 14.4	EG: 32.4 ± 10.1; CG: 35.6 ± 8.2	Freestyle swim training; 30-40 min/session; 3 sessions/week; 8 weeks.	Maintain daily routine, without structured exercise.	8UG 6MWT

Perrot A (2021) [47]	RCT	France	DS	EG: 6; CG: 6.	EG: 3/3; CG: 3/3	EG: 49.3 ± 8.2; CG: 51.4 ± 6.7	EG: NI CG: NI	EG: NI CG: NI	EG: 26.2 ± 5.8; CG: 28.6 ± 5.0	Wii-based exergaming program; 60 min/ session; 2 sessions/ week; 12 weeks.	Maintain daily routine, without structured exercise.	TUG 6MWT
Büyükçelik NM (2023) [48]	RCT	Turkey	DS	EG: 13; CG: 14	EG: 4/9; CG: 5/9	EG: 12.1 ± 2.6; CG: 11.9 ± 4.1	EG: 128.0 ± 18.39; CG: 130.3 ± 17.0	EG: 32.0 ± 13.9; CG: 35.3 ± 14.5	EG: 22.0 ± 3.1; CG: 24.4 ± 4.3	Dual-task balance exercises; 30 min/ session; 2 sessions/ week; 8 weeks.	Maintain daily routine, without structured exercise.	TUG

F: female; M: male; n: number; SD: standard deviation; cm: centimeter; BM: body mass; kg: kilogram; BMI: body mass index; DS: Down syndrome; EG: experimental group; CG: control group; NI: no information; RCT: randomized controlled trial; 6MWT: 6-minute Walking Distance Test; 8UG: 8-foot Up and Go Test; TUG: Timed Up and Go Test.

cycle length (step length (right): F = 14.47, P = .002; step length (left): F = 5.15, P = .038). Additionally, significant changes in joint angular parameters were observed, including increased ankle dorsiflexion, knee flexion, and hip extension. For example, the right ankle showed a significant reduction in excessive dorsiflexion during the loading response phase (P = .044), while the left knee demonstrated increased flexion during the mid-stance, terminal stance, and initial swing phases (P < .05). Furthermore, improvements in pelvic synchronization and shoulder flexion were also reported.

Publication Bias

The funnel plots showed that results for 8UG and 6MWT were symmetrically distributed around the central axis. Most data points fell within the funnel boundaries, indicating a low risk of publication bias. Consistently, Egger's test further confirmed that there was no publication bias for 8UG (P = .270) and 6MWT (P = .217) (Supplementary Figure 1).

Sensitivity Analysis

Sensitivity analyses for the 8UG and 6MWT were applied to test the robustness of the meta-analysis. Leave-one-out approaches and alternative modeling strategies were employed in the sensitivity analyses. The results showed no significant changes in effect estimates, indicating that the findings are robust and reliable (Supplementary Figure 2).

Adverse Events

Three studies (38%) included in this review reported on adverse events and stated that no adverse events occurred in any of the structured physical exercise groups [41,42,44]. The remaining studies did not report any information about adverse events.

GRADE Certainty of Evidence

The GRADE approach was applied to evaluate evidence quality across outcomes, showing that two measures (8UG and 6MWT) were rated as low. The main reasons for downgrading included a small sample size (less than 400) and the nature of the structured physical exercise intervention, which made blinding impossible (Supplementary Table 5).

Discussion

This research evaluated the impact of structured exercise programs on gait performance among people with DS. Results demonstrated that structured physical exercise may have the potential to improve gait performance compared to control conditions (without structured physical exercise). These findings support the therapeutic value of structured exercise programs for promoting functional independence in people with DS. The beneficial effects of structured physical exercise on people with DS have been well documented. Structured physical exercise enhances postural control and balance, facilitating greater engagement in daily activities and leading to improved physical activity levels and quality of life [26-28]. In addition, structured physical exercise has a positive impact on mental health in individuals with DS [49]. The present study expands the existing evidence by confirming that physical exercise can also improve gait performance in individuals with DS.

While this meta-analysis showed statistically significant benefits in gait-related outcomes, it is essential to consider whether these changes reflect true functional changes beyond measurement error. A previous study introduced comprehensive frameworks that incorporate test-retest reliability, sensitivity, and minimal detectable change (MDC) to assess the robustness and clinical applicability of functional performance measures [50]. Although the included studies did not report MDC values, we interpreted the pooled effects with reference to MDC and minimal clinically important difference (MCID) thresholds reported in older adults and clinical populations, acknowledging that these benchmarks may not directly apply to individuals with DS. The observed 43.19-meter improvement in the 6MWT appears to fall within the range of clinically meaningful changes reported in these populations, suggesting potential clinical relevance [51,52]. However, as no population-specific MDC or MCID values have been established for individuals with DS, these interpretations should be made with caution. Future trials are encouraged to report test-retest reliability and to develop population-specific MDC and MCID values to improve clinical interpretability of intervention effects.

Motor impairments in individuals with DS are primarily caused by the abnormal development of the CNS [16,17]. In particular, reductions in the volume of brain structures involved in motor control, such as the cerebellum and hippocampus, decreased neuronal density, and impaired synaptic function have been observed [53,54]. These neurological abnormalities result in impaired balance and postural control, thereby further limiting gait performance [27,28]. Structured physical exercise interventions may help mitigate these impairments by promoting neuroplastic adaptations [54]. Physical exercise has been shown to facilitate synaptic reorganization, enhance motor cortex excitability, and promote functional compensation of damaged neural pathways in other populations with CNS dysfunction [55]. In addition, physical exercise modulates key neurotrophic pathways, such as brain-derived neurotrophic factor (BDNF), which supports neuroplasticity and synaptogenesis, and insulin-like growth factor 1 (IGF-1), which regulates vascular remodeling [56]. Although individuals with DS exhibit more profound structural abnormalities, targeted structured physical exercise interventions may still activate the latent plasticity of residual neural networks, providing a basis for motor function recovery [49,53].

The analysis of spatial parameters and joint kinematics also offers insights into these functional improvements. Increases in step length and joint mobility, like hip flexion and ankle dorsiflexion, indicate better lower limb coordination and fewer compensatory movements [57]. These changes may be due to better muscle activation, improved proprioceptive feedback, and more efficient neuromuscular control [58,59]. Improvements in pelvic synchronization and shoulder flexion also suggest better trunk stability, which helps maintain gait symmetry and lowers the energy cost of walking [60]. These changes match findings in other neurological groups, like those with CP and stroke, where targeted exercises have helped restore more efficient and coordinated gait patterns [61-63]. In addition, descriptive analyses indicated that structured physical exercise interventions led to meaningful improvements in TUG and walking speed across several studies. These functional gains further support the biomechanical improvements and suggest enhanced mobility and gait efficiency. However, due to methodological heterogeneity and a limited sample size, these outcomes were synthesized narratively.

Our findings highlight the therapeutic potential of physical exercise in the rehabilitation of individuals with DS. As a low-risk, cost-effective, and easily implementable non-pharmacological intervention, physical exercise may improve gait ability in individuals with DS, potentially facilitating neuroplastic adaptations that enhance motor control and preserve functional capacity [49,53,54]. Previous studies have shown that systematic strength, balance, aerobic and coordination training have significant effects on improving physical performance, and enhancing independent living ability [26-32]. Based on current evidence, structured physical exercise interventions can be

considered an essential component of rehabilitation strategies for individuals with DS. Moreover, individualized and phase-specific structured physical exercise prescriptions, tailored to individuals motor abilities, developmental stages, and associated comorbidities, are recommended to optimize therapeutic outcomes and improve long-term functional independence.

Limitations

Several limitations must be acknowledged. First, the overall sample size across the included studies was relatively small, falling well below the 400-participant threshold recommended by the GRADE Working Group for adequate precision; such insufficiency reduces statistical power, widens confidence intervals, increases the risk of Type II error, and limits the reliability and interpretability of pooled effect estimates. Moreover, although most studies reported BMI, information on other anthropometric variables, such as body weight and height, was incomplete. This lack of standardised baseline data may compromise comparability across trials and weaken both internal validity and external generalisability. Larger, well-designed trials with comprehensive baseline reporting are therefore needed to confirm this preliminary evidence and improve the precision of future meta-analysis estimates. Second, although statistical heterogeneity across pooled outcomes was low, considerable clinical heterogeneity was present among the included studies, particularly regarding the types and structures of physical exercise interventions. These variations may reduce comparability between studies and limit pooled effect estimates validity. Although we applied a random-effects model and sensitivity analyses where possible, heterogeneity remains a notable limitation that should be considered when interpreting the findings. While intervention characteristics were systematically extracted using the FITT framework (Frequency, Intensity, Time, and Type), the lack of standardized reporting on external training load, including total volume, session density, and progression, represents a critical methodological limitation. Previous research has emphasized that the absence of unified frameworks for quantifying external training load presents a major challenge for interpreting and comparing exercise interventions across studies [64]. In the present review, the high variability and insufficient detail in load-related parameters limited the possibility of conducting dose-response or subgroup analyses and may have affected the consistency of pooled estimates. Future trials are encouraged to adopt standardized external load quantification models to enhance methodological rigor, improve comparability across studies, and support more precise evidence synthesis. Third, only English-language studies were included in this review, which may introduce language bias and limit the comprehensiveness of the evidence base. Although this decision facilitated standardized data extraction and methodological consistency, it may have excluded relevant findings published in other languages. Future systematic reviews should consider incorporating multilingual databases to enhance inclusivity and minimize potential selection bias.

Practical Applications

Structured physical exercise may represent a promising component of gait rehabilitation for individuals with DS, although current evidence remains preliminary and of low certainty. Clinicians and therapists are encouraged to design individualized training programmes that target specific gait impairments, while acknowledging existing research limitations. To optimize intervention outcomes, rehabilitation programmes could adopt a multidimensional approach that integrates physical, cognitive, and social engagement. Activities such as dance, interactive games, and group-based exercises may support motor skill development, while also enhancing motivation, adherence, and social interaction. These strategies should be implemented cautiously and validated in future high-quality trials.

Rehabilitation strategies should also be adapted to community settings to enhance their feasibility outside clinical settings. Active involvement of family members and caregivers can improve participant compliance and help extend intervention continuity into daily routines.

Early implementation of structured physical exercise may support more favorable motor development trajectories, though this hypothesis requires further empirical validation. Long-term follow-up, including regular assessments of gait-related parameters such as walking speed, endurance, and coordination, is recommended to track progress, adjust intervention intensity, and sustain functional gains over time.

Conclusion

The findings of this study indicated that structured physical exercise interventions may have the potential to improve gait-related outcomes in individuals with DS. Structured physical exercise programs may therefore serve as an effective strategy to optimize gait performance and promote functional independence in this population. However, the evidence was rated as low, primarily due to limited sample sizes and the inability to blind participants and personnel. Moreover, a lack of consistency regarding exercise types, dosages, and across studies presents additional challenges to the strength, reproducibility, and clinical applicability of the findings. These limitations collectively constrain the generalizability of current evidence and underscore the need for methodologically robust studies. Future research should determine the most effective exercise modalities, intensities, durations, and individualized intervention strategies tailored to participants' age and functional profiles, in order to establish more conclusive and clinically actionable recommendations for gait rehabilitation for individuals with DS.

Acknowledgments

Not applicable.

Informed Consent Statement

Not applicable.

Ethical Committee approval

Not applicable.

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Topic

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Conflicts of interest

The authors have no conflicts of interest to declare.

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Author-s contribution

Conceptualization: GP. Q; Methodology: GP. Q; Software: GP. Q, and Y. W; Validation: GP. Q, SJ. M; Formal analysis: GP. Q; Investigation: GP. Q; Resources: GP. Q and SJ. M; Data curation: GP. Q, HL. Y and SJ. M; Visualization: GP. Q and Y. W; Supervision: HL. Y and Z. O and YT. N; Project administration: Z. O; Writing-original draft: GP. Q; Writing-review and editing: GP. Q, HL. Y, Z. O and YT. N; All authors have read and agreed to the published version of the manuscript.

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