Research Report

Effectiveness of Rehabilitation Interventions to Improve Gait Speed in Children With Cerebral Palsy: Systematic Review and Meta-analysis

Noelle G. Moreau, Amy Winter Bodkin, Kristie Bjornson, Amy Hobbs, Mallary Soileau, Kay Lahasky

Background. Children with cerebral palsy (CP) have decreased gait speeds, which can negatively affect their community participation and quality of life. However, evidence for effective rehabilitation interventions to improve gait speed remains unclear.

Purpose. The purpose of this study was to determine the effectiveness of interventions for improving gait speed in ambulatory children with CP.

Data Sources. MEDLINE/PubMed, CINAHL, ERIC, and PEDro were searched from inception through April 2014.

Study Selection. The selected studies were randomized controlled trials or had experimental designs with a comparison group, included a physical therapy or rehabilitation intervention for children with CP, and reported gait speed as an outcome measure.

Data Extraction. Methodological quality was assessed by PEDro scores. Means, standard deviations, and change scores for gait speed were extracted. General study information and dosing parameters (frequency, duration, intensity, and volume) of the intervention were recorded.

Data Synthesis. Twenty-four studies were included. Three categories of interventions were identified: gait training (n=8), resistance training (n=9), and miscellaneous (n=7). Meta-analysis showed that gait training was effective in increasing gait speed, with a standardized effect size of 0.92 (95% confidence interval=0.19, 1.66; *P*=.01), whereas resistance training was shown to have a negligible effect (effect size=0.06; 95% confidence interval=−0.12, 0.25; *P*=.51). Effect sizes from negative to large were reported for studies in the miscellaneous category.

Limitations. Gait speed was the only outcome measure analyzed.

Conclusions. Gait training was the most effective intervention in improving gait speed for ambulatory children with CP. Strength training, even if properly dosed, was not shown to be effective in improving gait speed. Velocity training, electromyographic biofeedback training, and whole-body vibration were effective in improving gait speed in individual studies and warrant further investigation.

N.G. Moreau, PT, PhD, Department of Physical Therapy, Louisiana State University Health Sciences Center, 1900 Gravier St, 7th Floor, New Orleans, LA 70112 (USA). Address all correspondence to Dr Moreau at: Nmorea@lsuhsc.edu.

A.W. Bodkin, PT, PhD, Department of Physical Medicine and Rehabilitation, University of Colorado Anschutz Medical Campus, Aurora, Colorado.

K. Bjornson, PT, PhD, Department of Pediatrics, University of Washington, Seattle Children's Research Institute, Seattle, Washington.

A. Hobbs, PT, DPT, Department of Physical Therapy, Louisiana State University Health Sciences Center.

M. Soileau, PT, DPT, Department of Physical Therapy, Louisiana State University Health Sciences Center.

K. Lahasky, PT, DPT, Department of Physical Therapy, Louisiana State University Health Sciences Center.

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Cerebral palsy (CP) is the most prevalent physical disability in children, affecting 3.6 per 1,000 live births in the United States.[1] The motor impairments are often accompanied by sensory, cognitive, communication, and perceptual deficits, among others. According to the World Health Organization's *International Classification of Functioning, Disability and Health* (ICF), there are 3 levels at which humans function: (1) the body or body part, (2) the entire person, and (3) the entire person in a social setting.[2] In CP, impairments at the level of body structure and functions can ultimately lead to activity limitations and participation restrictions in the community. Common motor impairments include spasticity, stiffness, co-contraction, weakness, decreased rate of force development, decreased power, and many others.[3–6] Due to these impairments at the body structure and function level, the activity of walking is often compromised in children with CP, which restricts their participation by negatively affecting their health and their ability to keep up with their peers.[7]

Gait speed, often referred to as the sixth vital sign,[8] is an easy-to-administer objective and valid measure of walking activity that is linked to functional ability and quality of life in children with CP.[9,10] Gait abnormalities, including reduced gait speed, are debilitating complications of CP. Mobility impairments and walking difficulties may severely limit a child's daily activities, affecting his or her quality of life and ability to interact socially.[11,12] Gait speed may be predictive of level of community ambulation and may be a valuable measure of disability.[9,13]

Because of the impact of reduced gait speed and other gait abnormalities on participation and quality of life, the main focus of physical therapy interventions is often on improving gait. Extensive reviews of the literature present a compilation of interventions applied to people with CP, but there are conflicting reports over which methods are most effective.[14–17] Most interventions can be classified as either impairment-based or task-specific. Task-specific interventions, such as gait training or body-weight–supported treadmill training, aim to produce functional improvements in gait by providing repetitive stepping practice. Systematic literature reviews reported that treadmill training and the use of body-weight support show promise as interventions in children with CP for improving gait speed and gross motor function. However, the quality of evidence is weak, with a lack of randomized clinical trials in this area.[16,17] Since these reviews, multiple randomized controlled trials (RCTs) have been published on this subject, warranting further investigation into the effectiveness of these interventions.[18–21]

In contrast to task-specific interventions, impairment-based interventions focus on treating the impairments of body structure and function that are believed to create a functional or activity limitation. Because muscle weakness is a significant impairment in children with CP and muscle strength has been shown to be highly correlated to gait speed and locomotor ability,[5,6,22] strength training, one type of resistance training, is a common impairment-based intervention. However, evidence of the effectiveness of strength training in children with CP on function and activity limitations is conflicting. Scianni et al[15] conducted a systematic review to investigate the effects of strength training in children with CP and reported it to be ineffective in improving gait speed and function. Another systematic review[14] showed inconclusive results when investigating the effectiveness of strength training on improvements in gait speed in children with CP.

The evidence to support the use of rehabilitation interventions to increase gait speed in children with CP is limited and warrants further investigation. Furthermore, there is no general consensus as to which rehabilitation intervention is the most effective in increasing gait speed in children with CP. The majority of systematic literature reviews investigate the effects of a single intervention on multiple outcome measures at various levels of the ICF model. This systematic literature review is unique in that it is focused on a single outcome measure of great importance: gait speed. The purpose of this systematic literature review was to identify which interventions are most effective at increasing gait speed in children with CP.

Method

This study was a systematic literature review and meta-analysis of the available literature reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement and guidelines.[23]

Search Strategy

This systematic review contains studies that were published from the earliest available date (1952) through April 2014. An electronic database search was performed in MEDLINE/PubMed, ERIC, CINAHL, and PEDro using the following search terms: (cerebral palsy) AND (gait OR walking). Broad search terms were used to ensure that all articles with potential for inclusion in this review were evaluated. Results were limited to English language articles.

The titles and abstracts of articles identified by the electronic search were assessed by 3 of the authors to determine whether the article met our inclusion criteria (listed below). In the case of disagreement, a fourth author was consulted. If the title or abstract did not provide sufficient information to determine eligibility, the article was obtained to determine whether it met the criteria. The numbers of articles that were excluded and reasons for exclusion are detailed in Figure 1.

Eligible Studies

In order to be included in the systematic literature review, studies had to have an experimental design with a comparison or control group (eg, an RCT), include participants who were ambulatory and under the age of 18 years with a diagnosis of CP (both experimental and control groups), include a physical therapy or rehabilitative intervention as the experimental condition, and report gait speed as an outcome measure. Other acceptable terms for gait speed included "walking speed," "gait velocity," and "walking velocity." Studies were excluded if the entire intervention took place during a

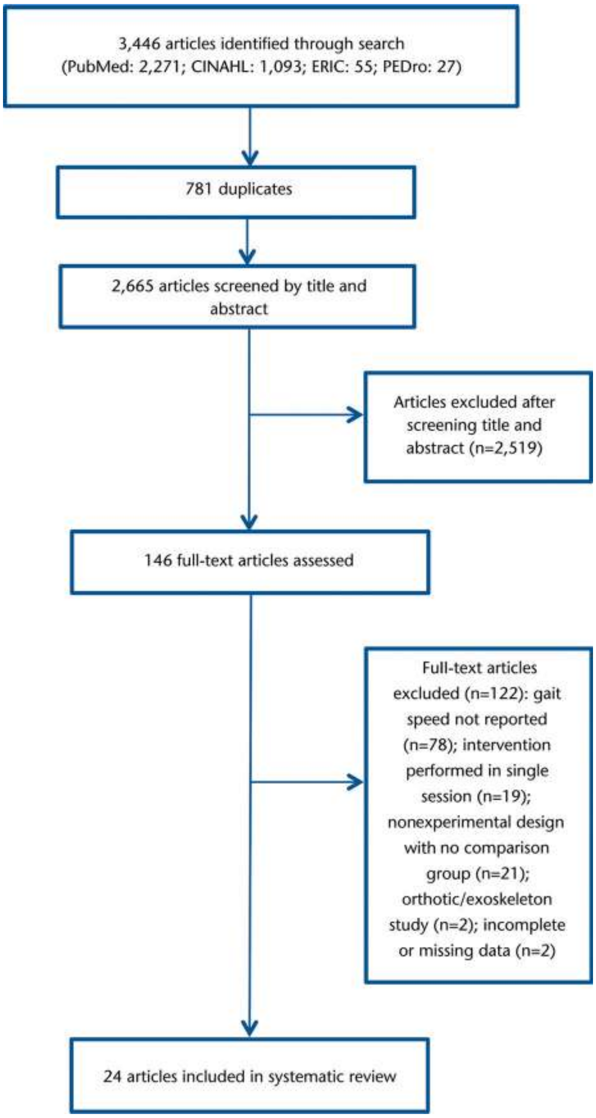

Figure 1.
Flowchart of study selection.

single session or if orthotic devices were the primary intervention rather than an adjunctive intervention.

Quality Assessment

Studies that met the inclusion criteria were assessed for methodological quality using the PEDro scale.[24] Each indicator of methodological rigor was scored independently by 3 of the authors, with criteria 2 through 11 of the PEDro scale used for scoring purposes. This process resulted in a total score between 0 and 10 for the 24 articles included in this review. Discrepancies in any of the criteria were resolved through discussion and a fourth rater, resulting in 100% agreement. According to an article's score on the PEDro scale, the article was assigned a rating as follows: excellent (9–10), good (6–8), fair (4–5), or poor (<4).

Data Extraction and Analysis

Data were extracted from each of the studies by 3 of the reviewers independently and cross-checked to eliminate any errors. The articles were divided into categories based on the type of intervention the participants received in order to compare effectiveness across interventions for increasing gait speed in children with CP. The following categories were used: gait training, resistance training, and miscellaneous. The miscellaneous category included all other types of interventions that met the inclusion and exclusion criteria but could not be grouped together due to the number of articles (≤3). We had 100% agreement on the categorization of the articles. Means and standard deviations for preintervention and postintervention measures of self-selected gait speed were extracted. Mean change was calculated where not reported. For purposes of this review article, gait speed refers to self-selected gait speed as the primary outcome used for analysis. If fast gait speed was reported in addition to self-selected gait speed, it also was recorded to provide supplemental information.

Standardized effect sizes with 95% confidence intervals (95% CIs) were calculated to allow comparisons among different interventions. Whenever change scores and the standard deviation of the change score were provided, we used the preferred method of effect size calculation: the difference in mean change scores for gait speed between the experimental and control groups divided by the pooled standard deviation of the change scores. When this information was not provided in the article, we used the difference of the mean posttraining gait speed between the experimental and control groups divided by the pooled standard deviation of the gait speed variable. Bias-corrected effect sizes for small sample sizes were calculated using the Hedges' g correction.[25] Effect sizes favoring the experimental group were positive, and those favoring the control or comparison group were negative, with an effect size of 0 indicating no difference between groups. An effect size of less than 0.20 was considered trivial, 0.20 to 0.49 was considered a small effect, 0.50 to 0.79 was considered a medium effect, and 0.80 and above was considered a large effect.[26]

In order to quantify effects of different interventions on gait speed, we conducted separate random-effects meta-analyses for the intervention categories of gait training and resistance training.[27] The different types of interventions and small number of articles included in the miscellaneous category were not appropriate for a meta-analysis. Thus, an overall Hedges' g effect size, 95% CI, and *P* value were calculated separately for the categories of gait training and resistance training to allow comparison of these 2 types of interventions. The meta-analysis included RCTs that compared the experimental intervention with no intervention, usual activities, conventional physical therapy, or other comparison intervention. If the comparison intervention belonged in the same category as the experimental intervention (ie, comparison of 2 different types of gait training), the meta-analysis results were reported with and without the inclusion of these studies. The weight of each study was calculated as $1/V_y$, where V_y represents the within-study variance plus the between-studies variance. Relative weight was calculated as a percentage of the overall sum of weights. Statistical heterogeneity of variance was quantified by the I^2 statistic and Q statistic. Forest plots were used to graphically illustrate the results of the meta-analyses.[28]

The effectiveness of the intervention in each study was assessed by 4 parameters: between-groups effect sizes with meta-analysis, within- and between-groups statistical significance, and determining whether the mean change in speed met the minimal clinically important difference (MCID) for gait speed (0.1 m/s) for children with CP.[29] The MCID represents the amount of change necessary to be considered clinically meaningful. The MCID was used to strengthen the assessment of the literature because results that are statistically significant may not be clinically meaningful.

Role of the Funding Source

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Results

The search strategy identified 3,446 articles, including 781 duplicate publications. After screening both abstracts and titles, 146 full-text articles were retrieved. After reviewing the articles to determine whether they met all of the inclusion criteria, 24 studies remained and were included in the review. Refer to Figure 1 for details of the flow of studies throughout the review.

Methodological Quality

Overall, PEDro scores ranged from 3 to 8, with an average score of 6.21 and a median score of 6. Of the 24 studies, none were rated excellent, 16 (71%) were rated good, 7 (30%) were rated fair, and 1 (4%) was rated poor. There were several items on the PEDro scale that were frequently not fulfilled among the studies included in this review. The categories of participant blinding and therapist blinding were not included on any of the studies. Forty-two percent of the studies did not conceal allocation, and 46% did not perform an intention-to-treat analysis.

Categories of Intervention Summaries

The 24 studies were divided into the 3 intervention categories: gait training (8 studies), resistance training (9), and miscellaneous (7). A general description of the 24 studies is presented in Table 1, including information about the study design, participant demographics, intervention, dosing parameters, and outcome measure used to calculate gait speed. Table 2 details information relating to methodological quality, results, and effect sizes.

Gait training. Our systematic literature review identified 8 studies (33%) (n=201 participants) that investigated the effectiveness of gait training on gait speed in children with CP (Tab. 1).[18–21,30–33] Scores on the PEDro for the articles in this category ranged from 4 to 8, with an overall average rating of 6.5 and median of 7. Of the 8 studies included in this category, 5 (62%) were rated good[18–20,30,32] and 3 (38%) were rated fair.[21,31,33] The mean change in gait speed for gait training ranged from 0.01 to 0.26 m/s, with effect sizes ranging from −0.17 to 3.20 (Tab. 2). Effect sizes for studies that performed gait training with body-weight support[18,21,30,31,33] ranged from −0.17 to 0.82, and effect sizes for studies without body-weight support[19,20,32] ranged from 1.32 to 3.20. In this category, 4 articles (50%) met or exceeded the MCID,[19–21,32] 3 (38%) reported within-group statistical significance,[18,20,32] and 4 (50%) reported between-groups statistical significance.[18–20,31] (see Tab. 2 for details).

The reported age range of participants in the gait training studies was between 5 and 17 years. The included studies investigated the effectiveness of gait training with[18,21,30,31,33] and without[19,20,32] body-weight support, including robotic-assisted treadmill training,[30] overground "talking" pedometer-based gait training,[20] and treadmill training without body-weight support but with auditory and visual feedback[32] (Tab. 2, gait training). Dosing of training was variable across all studies, ranging from a frequency of 2 to 5 sessions per week over a duration of 2 to 12 weeks. In the 3 studies without body-weight support,[19,20,32] children trained for a total of 12 weeks at a frequency of 3 to 5 sessions per week. Dosing for the 5 studies that used partial body-weight support ranged from a frequency of 2 to 5 times per week over a duration of 2 to 12 weeks with a lower total number of sessions (10–20) reported. Three of these 5 studies were of fair quality.[21,31,33] The intensity of gait training (speed) was either not reported or reported as individually determined speeds. Volume of training per session ranged from individually defined duration based on level of fatigue up to a total of 45 minutes per session, with total number of sessions ranging from 10 to 33 (see Tab. 1 for details).

Resistance training. In this systematic literature review, 9 studies (38%)

Table 1.
Study Characteristics and Dosing[a]

Reference	Study Design	Group	Sample Size, Sex	Age (y) $\overline{X}$ (SD) [Range]	GMFCS Level	Diagnosis	Intervention	Frequency/ Duration (wk)	Total Sessions (SD)	Intensity and Volume	Walking Test/Distance
Gait training											
Dodd and Foley, 2007[31]	CCT	TxG	n=7; 5 M, 2 F	8.4 (2.5) [6–14]	III (2), IV (5)	Athetoid quadriplegia (4), spastic diplegia (1), spastic quadriplegia (2)	PBWSTT	2/6	11.4 (0.98)	30 min maximum, median maximum speed=0.6 kph (range=0.4–1.1)	10MWT
		CG	n=7; 5 M, 2 F	9.4 (2.8) [5–12]	III (2), IV (5)	Athetoid quadriplegia (4), spastic diplegia (1), spastic quadriplegia (2)	NR	NR	NR	NR	10MWT
Willoughby et al, 2010[33]	RCT	TxG	n=12; 6 M, 6 F	10.4 (3.14)	III (5), IV (7)	CP (type NR)	PBWSTT	2/9	13.33 (2.02)	30 min maximum, individualizing, initial speed=0.38 m/s, final speed=0.59 m/s	10MWT
		CG	n=14; 9 M, 5 F	11.2 (4.17)	III (3), IV (11)	CP (type NR)	Overground walking	2/9	14.21 (2.19)	30 min maximum, initial speed=0.18 m/s, final speed=0.24 m/s	10MWT
Gharib et al, 2011[32]	RCT	TxG	n=15; 10 M, 5 F	11.9 (1.06)	II (15)	Spastic hemiplegia	Biodex Gait Trainer 2 + traditional PT	3/12	NR	PT for 30 min, GT for 15 min	GT
		CG	n=15; 6 M, 9 F	11.2 (1.11)	II (15)	Spastic hemiplegia	Traditional PT	3/12	NR	30 min	GT
Hamed and Abd-elwahab, 2011[20]	RCT	TxG	n=15 (30 total; 17 M, 13 F)	7.0 (0.76)	NR	Spastic hemiplegia	Traditional PT + gait training with pedometer	5/12	NR	1 h NDT + gait program with pedometer	3-D motion analysis/8 m
		CG	n=15; NR	7.1 (0.82)	NR	Spastic hemiplegia	Traditional PT + gait training without pedometer	5/12	NR	1 h NDT + gait program without pedometer	3-D motion analysis/8 m
Johnston et al, 2011[21]	RCT	TxG	n=14; 7 M, 7 F	9.6 (2.2)	II (1), III (9), IV (4)	Spastic diplegia (8), quadriplegia (6)	Supported speed stepping (PBWSTT)	5/12; 2 wk: 30 min, 2×/d; 10 wk: 30 min, 5 d/wk	≥80%	Individualized Initial treadmill speed=0.36 m/s Final treadmill speed=0.64 m/s	3-D gait analysis
		CG	n=12; 7 M, 5 F	9.5 (2.3)	II (1), III (6), IV (5)	Spastic diplegia (4), triplegia (2), quadriplegia (6)	Exercise program (strengthening and standing activities)	5/12; 2 wk: 30 min, 2×/d; 10 wk: 30 min, 5 d/wk	NR	Individualized	3-D gait analysis

(Continued)

Table 1.
Continued

Reference	Study Design	Group	Sample Size, Sex	Age (y) $\overline{X}$ (SD) [Range]	GMFCS Level	Diagnosis	Intervention	Frequency/ Duration (wk)	Total Sessions (SD)	Intensity and Volume	Walking Test/Distance
Smania et al, 2011[18]	RCT	TxG	n=9; 5 F, 4 M	13.9 (2.83) [10–17]	I (3), II (2), III (0), IV (4)	Spastic tetraplegia (4), diplegia (5)	EGT with PBWS + passive joint mobilization and stretching	5/2	10	30 min EGT, 10 min passive joint mobilization/stretching Speed: NR	10MWT
		CG	n=9; 3 F, 6 M	12.8 (3.08) [8–17]	I (3), II (0), III (3), IV (3)	Spastic tetraplegia (3), diplegia (6)	Conventional PT: stretching, strengthening, balance and gait exercises	5/2	10	40 min: 10 min stretching, 15 min balance and gait exercises, 15 min strengthening	10MWT
Chrysagis et al, 2012[19]	RCT	TxG	n=11; 6 M, 5 F	15.9 (1.97) [13–19]	I–II (7), III (4)	Spastic diplegia (9), spastic tetraplegia (2)	Treadmill training (without BWS)	3/12	29.5 (2.84)	30 min; self-selected speed	10MWT
		CG	n=11; 7 M, 4 F	16.1 (1.51) [14–18]	I–II (7), III (4)	Spastic diplegia (10), spastic tetraplegia (1)	Conventional PT (mat activities, balance, GT, functional gross motor activities)	3/12	NR	3 sets, 45 min	10MWT
Druzbicki et al, 2013[30]	RCT	TxG	n=26; NR	10.1 (2.2)	II (15), III (11)	Spastic diplegia	Active orthosis exercise program (Lokomat, Hocoma Inc USA, Norwell, MA) with PBWSTT + individual PT exercise program	NR	20	45 min Device speed range: 1–3.2 kph	3-D gait analysis
		CG	n=9; NR	11.0 (2.3)	II (8), III (1)	Spastic diplegia	Individual PT exercise program	NR	20	45 min	3-D gait analysis
Resistance training											
Dodd et al, 2003[41]	RCT	TxG	n=11, 4 M, 7 F	12.7 (2.8) [6–15]	I (2), II (2), III (7)	Spastic diplegia	Strength training: ankle PF, knee and hip extensors (heel raises, squats, step-ups)	3/6	16.7 (2.4)	65%–80% 1RM* 3 sets of 8–10 reps	10MWT
		CG	n=10; 6 M, 4 F	13.5 (3.4) [5–12]	I (5), II (3), III (2)	Spastic diplegia	Normal daily activities	N/A	N/A	N/A	10MWT
Engsberg et al, 2006[38]	RCT	TxG	n=9; 2 M, 7 F	9.9 (3.52)	I (4), II (3), III (2)	Spastic diplegia	Strength training: isokinetic (concentric and eccentric) ankle PF, DF, or PF and DF	3/12	36	80%–100% 1RM 3 sets of 5 reps at 30°/s, 3 sets of 5 reps at 90°/s	3-D gait analysis/3 m
		CG	n=3; 1 M, 2 F	10.7 (2.2)	I (1), II (2)	Spastic diplegia	No intervention	N/A	N/A	N/A	3-D gait analysis/3 m

(Continued)

Table 1.
Continued

Reference	Study Design	Group	Sample Size, Sex	Age (y) $\overline{X}$ (SD) [Range]	GMFCS Level	Diagnosis	Intervention	Frequency/ Duration (wk)	Total Sessions (SD)	Intensity and Volume	Walking Test/Distance
Unger et al, 2006[37]	RCT	TxG	n=21; 13 M, 8 F	15.9 [13.5–18.9]	NR	Spastic hemiplegia (8), diplegia (12), triplegia (1)	Strength training upper and lower limbs and trunk using body weight; various free weights; elastic and resistance bands	1–3/8	NR	65%–85% 1RM* 3 sets of 12 reps; 8–12 exercises from 28 station UE/LE circuit	3-D gait analysis/NR
		CG	n=10; 6 M, 4 F	16.3 [14.0–18.3]	NR	Spastic hemiplegia (8), diplegia (2)	No intervention	N/A	N/A	N/A	3-D gait analysis/NR
Liao et al, 2007[40]	RCT	TxG	n=10; 7 M, 3 F	7.1 (1.7)	I (4), II (6)	Spastic diplegia	Loaded STS + conventional PT (PROM, positioning, balance training, NDT)	3×/d 3/6	18.0 (3.2)	STS 10 times with 20% 1RM, STS until fatigued with 50% 1RM, 10 STS with 20% 1RM	10MWT
		CG	n=10; 5 M, 5 F	7.6 (1.5)	I (6), II (4)	Spastic diplegia	Conventional PT (PROM, positioning, balance training, NDT)	6 wk	NR	NR	10MWT
Lee et al, 2008[34]	RCT	TxG	n=9; 4 M, 5 F	6.3 (2.1)	II–III	Spastic diplegia (4), hemiplegia (5)	Strength training of multiple muscle groups (squat-to-stand transfer, lateral step-up, stairs, isotonic, isokinetic bicycle)	3/5	NR	75% 1RM* 60 min: 2 sets of 10 reps for isotonic	3-D gait analysis/NR
		CG	n=8; 6 M, 2 F	6.3 (2.9)	II–III	Spastic diplegia (5), hemiplegia (3)	Conventional PT	NR/5	NR	NR	3-D gait analysis/NR
Pandey and Tyagi, 2011[35]	RCT	TxG	n=9; NR	NR [5–10]	NR	Spastic diplegia	Strength training of multiple muscle groups; heel raises; sit-to-stand transfer; step-up; standing balance; ball half-squat	2/4	NR	NR 1-h sessions	10MWT
		CG	n=9; NR	NR [5–10]	NR	Spastic diplegia	No intervention	N/A	N/A	N/A	10MWT
Scholtes et al, 2012[39]	RCT	TxG	n=24; 8 F, 16 M	10.3 (0.83)	I (13), II (8), III (3)	Spastic unilateral (7), bilateral (17)	Strength training; functional using sit-to-stand transfer, lateral step-ups, half knee-rise	3/12	NR	BW to 80% 1RM* 3 sets of 8 reps	10MWT
		CG	n=25; 12 F, 13 M	10.3 (2.25)	I (12), II (9), III (4)	Spastic unilateral (10), bilateral (15)	Conventional PT	1–3 per week	NR	NR	10MWT

(Continued)

Table 1.
Continued

Reference	Study Design	Group	Sample Size, Sex	Age (y) $\overline{X}$ (SD) [Range]	GMFCS Level	Diagnosis	Intervention	Frequency/ Duration (wk)	Total Sessions (SD)	Intensity and Volume	Walking Test/Distance
Moreau et al, 2013[36]	RCT	TxG	n=9; 4 M, 5 F	13.9 (2.6)	I (5), III (4)	Spastic diplegia (4), hemiplegia (5)	Velocity (power) training of knee extensors; isokinetic (concentric) at 30–120°/s	3/8–10	24	Maximum effort 6 sets of 5 reps of knee extension	10MWT
		CG	n=7; 6 M, 1 F	13.7 (4.3)	I (4), II (1), III (2)	Spastic diplegia (4), hemiplegia (3)	Strength training of knee extensors; isokinetic (concentric) at 30°/s	3/8–10	24	Maximum effort 6 sets of 5 reps knee extension	10MWT
Taylor et al, 2013[42]	RCT	TxG	n=23; 13 M, 10 F	18.2 (1.92)	II (13), III (10)	Spastic diplegia	Strength training targeting multiple muscle groups using weight machines	2/12	21.9 (2.4)	65%–75% 1RM* 4–6 exercises, 3 sets of 10–12 reps	10MWT
		CG	n=25; 13 M, 12 F	18.6 (2.92)	II (16), III (9)	Spastic diplegia	Usual activities	N/A	N/A	N/A	10MWT
Miscellaneous											
van der Linden et al, 2003[43]	RCT	TxG	n=11; NR	8.5 (2.83) [5–14]	NR	Spastic diplegia (6), quadriplegia (1), hemiplegia (4)	Electrical stimulation to gluteus maximus muscle of most affected leg + normal PT/HEP	6/8	NR	1 h/d: 0.8 s ramp-up, on-off cycle 5–15 s	3-D gait analysis/NR
		CG	n=11; NR	8.2 (2.92) [5–14]	NR	Spastic diplegia (8), hemiplegia (3)	Normal PT/HEP	NR	NR	NR	3-D gait analysis/NR
Dursun et al, 2004[45]	RCT	TxG	n=21; 8 F, 13 M	8.9 (4.95) [6–19]	NR	Spastic diplegia (9), hemiplegia (12)	EMG biofeedback training + conventional PT program	10 d	NR	EMG 30 min/d + exercise for 2 h/d	Videotape analysis/NR
		CG	n=11; 4 F, 7 M	8.8 (4.84) [6–19]	NR	Spastic diplegia (5), hemiplegia (6)	Conventional PT program	10 d	NR	Exercise for 2.5 h/d	Videotape analysis/NR
van der Linden et al, 2008[44]	RCT	TxG	n=7; NR	8.0 [5–13]	NR	Spastic diplegia (3), hemiplegia (3), monoplegia (1)	NMES + FES (foot drop stimulator) during normal activities	NMES 6/2 + FES 7/8	NR	NMES 1 h/d FES worn all day at 40 Hz	3-D gait analysis/NR
		CG	n=7; NR	8.14 [5–11]	NR	Spastic diplegia (3), hemiplegia (3), monoplegia (1)	Continued usual PT program	NR	NR	NR	3-D gait analysis/NR

(Continued)

Table 1.
Continued

Reference	Study Design	Group	Sample Size, Sex	Age (y) $\overline{X}$ (SD) [Range]	GMFCS Level	Diagnosis	Intervention	Frequency/ Duration (wk)	Total Sessions (SD)	Intensity and Volume	Walking Test/Distance
Fowler et al, 2010[46]	RCT	TxG	n=31; 18 M, 13 F	11.1 (3.41) [7–18]	I (11), II (8), III (12)	Spastic diplegia	Stationary cycling	3/12	89.6% of 30	60 min	30SWT
		CG	n=31; 11 M, 20 F	11.6 (2.84) [7–18]	I (8), II (6), III (17)	Spastic diplegia	No intervention	N/A	N/A	N/A	30SWT
Arya et al, 2012[47]	RCT	TxG	n=5; 3 M, 2 F	8.8 (2.21) [7–14]	2.75 (0.95)	Spastic hemiplegia or diplegia	NMES to QF and TA + PT/OT and (stretching, strengthening, and positioning exercises + ADL based on age)	4–5/4	NR	20–30 min/d; 20 Hz for QF and 40 Hz for TA	NR
		CG	n=5; 2 M, 3 F	9.3 (2.98) [7–14]	1.75 (0.5)	Spastic hemiplegia or diplegia	PT/OT and (stretching, strengthening, and positioning exercises + ADL based on age)	NR	NR	NR	NR
Lee and Chon, 2013[48]	RCT	TxG	n=15; 6 M, 9 F	10.0 (2.26)	NR	Spastic diplegia, quadriplegia	WBV + conventional PT (gentle massage, stretching, balance training)	3/8	NR	1 h: 10-min warm-up; 18-min WBV at various frequencies; 10-min cool-down	3-D gait analysis/NR
		CG	n=15; 9 M, 6 F	9.7 (2.58)	NR	Spastic diplegia, quadriplegia	Conventional PT (gentle massage, stretching, balance training)	NR	NR	30 min	3-D gait analysis/NR
Wang et al, 2013[49]	RCT	TxG	n=18; 12 M, 6 F	9.0 (1.99) [5–13]	I (9), II (4), III (5)	Spastic diplegia	Loaded STS with patterned sensory enhancement + continued usual care	3/6	17.8	10 STS at 20% 1RM, STS until fatigued at 50% 1RM, 10 STS at 20% 1RM with patterned sensory enhancement	10MWT
		CG	n=18; 15 M, 3 F	9.0 (2.61) [5–13]	I (9), II (3), III (6)	Spastic diplegia	Loaded STS + continued usual care	3/6	17.7	Same but without patterned sensory enhancement	10MWT

[a] GMFCS=Gross Motor Function Classification System, RCT=randomized controlled trial, 1RM=one-repetition maximum, M=male, F=female, 10MWT=10-Meter Walk Test, TxG=treatment group, CG=control group, CCT=controlled clinical trial, NR=not reported, N/A=not available, PT=physical therapy, CP=cerebral palsy, BWS=body-weight support, PBWSTT=partial body-weight–supported treadmill training, PBWS=partial body-weight support, PF=plantar flexors, DF=dorsiflexors, PROM=passive range of motion, NDT=neurodevelopmental treatment, UE=upper extremity, LE=lower extremity, NMES=neuromuscular electrical stimulation, FES=functional electrical stimulation, QF=quadriceps femoris, TA=tibalis anterior, OT=occupational therapy, ADL=activities of daily living, HEP=home exercise program, EMG=electromyography, 30SWT=30-Second Walk Test, 95% CI=95% confidence interval, WBV=whole-body vibration, GT=gait trainer, EGT=electromechanical gait trainer, reps=repetitions, STS=sit-to-stand transfer, 3-D=3-dimensional. Walking test/distance refers to both self-selected and fast gait speeds when both were measured. * Estimated percentage of 1RM.

Table 2.
Study Quality, Gait Speed Outcomes, and Effect Sizes by Category[a]

Reference	Group	Intervention	PEDro Score	Mean Pretraining Speed (SD) (m/s)	Mean Posttraining Speed (SD) (m/s)	Mean Δ Speed (m/s)	MCID	SS (Within Group)	SS (Between Groups)	Hedges' g Effect Size (95% CI)
Gait training										
Dodd and Foley, 2007[31]	TxG	PBWSTT	5 Fair	0.10 (0.12)	0.17 (0.15)	0.07	N	NR	Y	0.82 (−0.27, 1.91)
	CG	NR		0.13 (0.07)	0.13 (0.10)	0.002	N	NR		
Willoughby et al, 2010[33]	TxG*	PBWSTT	5 Fair	0.56 (0.34)	0.56 (0.39)	0.01	N	NR	N	−0.15 (−0.92, 0.62)
	CG*	Overground walking		0.30 (0.23)	0.34 (0.27)	0.04	N	NR		
Gharib et al, 2011[32]	TxG	GT	8 Good	0.53 (0.09)	0.67 (0.09)	0.14	Y	Y	N	1.80 (0.95, 2.65)
	CG	PT		0.53 (0.10)	0.63 (0.103)	0.09	N	Y		
Hamed and Abd-elwahab, 2011[20]	TxG*	PT+GT+ped	8 Good	0.42 (0.09)	0.68 (0.09)	0.26	Y	Y	Y	3.20 (2.12, 4.28)
	CG*	PT+GT		0.39 (0.08)	0.45 (0.11)	0.06	N	Y		
Johnston et al, 2011[21]	TxG	PBWSTT	4 Fair	0.50 (0.26)	0.62 (0.31)	0.12	Y	N	N	0.33 (−0.44, 1.11)
	CG	Exercise		0.44 (0.35)	0.50 (0.39)	0.06	N			
Smania et al, 2011[18]	TxG	EGT-PBWS	8 Good	0.89 (0.27)	0.97 (0.31)	0.08	N	Y	Y	0.53 (−0.41, 1.47)
	CG	PT		0.85 (0.25)	0.82 (0.22)	0.03	N	N		
Chrysagis et al, 2012[19]	TxG	Treadmill, no BWS	8 Good	0.83 (0.23)	1.00 (0.15)	0.17	Y	NR	Y	1.32 (0.40, 2.24)
	CG	PT		0.77 (0.18)	0.78 (0.17)	0.01	N	NR		
Druzbicki et al, 2013[30]	TxG	Lokomat PBWSTT	6 Good	0.34 (0.14)	0.36 (0.18)	0.02	N	NR	N	−0.17 (−0.93, 0.59)
	CG	PT		0.35 (0.14)	0.39 (0.18)	0.04	N	NR		

(Continued)

Table 2.
Continued

Reference	Group	Intervention	PEDro Score	Mean Pretraining Speed (SD) (m/s)	Mean Posttraining Speed (SD) (m/s)	Mean Δ Speed (m/s)	MCID	SS (Within Group)	SS (Between Groups)	Hedges' g Effect Size (95% CI)
Resistance training										
Dodd et al, 2003[41]	TxG	Strength training	7 Good	0.79 (0.39)	0.8 (0.35)	0.01	N	N	N	−0.11 (−0.97, 0.75)
	CG	No IV		0.83 (0.41)	0.84 (0.35)	0.02	N	N		
Engsberg et al, 2006[38]	TxG	Strength training	3 Poor	0.86 (0.31)	0.91 (0.35)	0.05	N	N	NR	0.32 (−0.99, 1.64)
	CG	No IV		0.80 (0.23)	0.79 (0.31)	−0.02	N	N/A		
Unger et al, 2006[37]	TxG	Strength training	6 Good	1.08 (0.24)	1.12 (0.23)	0.04	N	NR	N	−0.24 (−0.99, 0.52)
	CG	No IV		1.13 (0.13)	1.17 (0.14)	0.04	N	NR		
Liao et al, 2007[40]	TxG	Loaded STS+PT	5 Fair	0.95 (0.28)	1.02 (0.09)	0.07	N	NR	N	0.43 (−0.46, 1.31)
	CG	PT		1.06 (0.16)	0.98 (0.09)	−0.08	N	NR		
Lee et al, 2008[34]	TxG	Strength training	5 Fair	0.55 (0.31)	0.75 (0.39)	0.20	Y	NR	Y	0.16 (−0.79, 1.12)
	CG	PT		0.70 (0.43)	0.68 (0.43)	−0.02	N	NR		
Pandey and Tyagi, 2011[35]	TxG	Strength training	4 Fair	0.54 (0.08)	0.7 (0.1)	0.16	Y	Y	NR	0.95 (−0.02, 1.93)
	CG	No IV		0.59 (0.09)	0.6 (0.1)	0.01	N	N		
Scholtes et al, 2012[39]	TxG	Strength training	7 Good	SSS=0.95 (0.29) FS=1.29 (0.45)	SSS=1.03 (0.33) FS=1.34 (0.48)	SSS=0.08 FS=0.05	N N	N N	N	SSS=−0.11 (−0.66, 0.44) FS=0.24 (−0.31, 0.79)
	CG	PT		SSS=0.95 (0.28) FS=1.25 (0.39)	SSS=1.07 (0.38) FS=1.23 (0.43)	SSS=0.12 FS=−0.02	Y N	N		
Moreau et al, 2013[36]	TxG*	Velocity training	6 Good	SSS=0.98 (0.41) FS=1.34 (0.58)	SSS=1.08 (0.46) FS=1.46 (0.67)	SSS=0.10 FS=0.12	Y Y	Y Y	NR	SSS=0.44 (−0.56, 1.44) FS=0.48 (−0.52, 1.49)
	CG*	Strength training		SSS=1.23 (0.23) FS=1.60 (0.34)	SSS=1.27 (0.26) FS=1.63 (0.34)	SSS=0.04 FS=0.03	N	N	NR	
Taylor et al, 2013[42]	TxG	Strength training	8 Good	0.94 (0.34)	0.95 (0.34)	0.01	N	N	N	0.09 (−0.48, 0.57)
	CG	No IV		0.90 (0.30)	0.91 (0.29)	0.01	N	N		

(Continued)

Table 2.
Continued

Reference	Group	Intervention	PEDro Score	Mean Pretraining Speed (SD) (m/s)	Mean Posttraining Speed (SD) (m/s)	Mean Δ Speed (m/s)	MCID	SS (Within Group)	SS (Between Groups)	Hedges' g Effect Size (95% CI)
Miscellaneous										
van der Linden et al, 2003[43]	TxG	Estim+PT	6 Good	0.96 (0.23)	0.97 (0.23)	0.01	N	NR	N	0.12 (−0.72, 0.96)
	CG	PT		0.94 (0.18)	0.94 (0.25)	0.00	N	NR		
Dursun et al, 2004[45]	TxG	EMG biofeedback+PT	6 Good	0.60 (0.34)	0.73 (0.37)	0.13	Y	Y	Y	0.84 (0.15, 1.53)
	CG	PT		0.45 (0.32)	0.46 (0.34)	0.01	N	Y		
van der Linden et al, 2008[44]	TxG	Estim	7 Good	0.93 (0.20)	1.01 (0.17)	0.08	N	NR	N	0.00 (−1.09, 1.09)
	CG	PT		1.01 (0.09)	1.01 (0.11)	0.00	N	NR		
Fowler et al, 2010[46]	TxG	Stationary cycling	6 Good	1.12 (0.37)	1.13 (0.34)	0.02	N	N	N	0.26 (−0.26, 0.78)
	CG	No IV		0.98 (0.36)	1.04 (0.34)	0.06	N	N		
Arya et al, 2012[47]	TxG	Estim+PT/OT	5 Fair	0.22 (0.08)	0.40 (0.11)	0.17	Y	Y	Y	1.96 (0.45, 3.46)
	CG	PT/OT		0.38 (0.10)	0.42 (0.06)	0.04	N	N		
Lee and Chon, 2013[48]	TxG	Whole-body vibration + PT	8 Good	0.37 (0.04)	0.48 (0.06)	0.11	Y	Y	Y	1.41 (0.61, 2.21)
	CG	PT		0.39 (0.05)	0.40 (0.05)	0.01	N	NR		
Wang et al, 2013[49]	TxG	PSE during STS+PT	8 Good	0.87 (0.3)	0.92 (0.35)	0.05	N	N	N	0.27 (−0.38, 0.93)
	CG	STS+PT		0.77 (0.35)	0.83 (0.37)	0.06	N	N		

[a] Δ=change, MCID=minimal clinically important difference, SS=statistical significance, TxG=treatment group, CG=control group, Y=yes, N=no, NR=not reported, N/A=not applicable, 95% CI=95% confidence interval, SSS=self-selected speed, FS=fast speed, GT=gait training, GT+Ped=GT+pedometer, PBWSTT=partial body-weight–supported treadmill training, PBWS=partial body-weight support, OGW=overground walking, IV=intervention, PSE=patterned sensory enhancement, STS=sit-to-stand transfer, PT=physical therapy, EGT=electromechanical gait trainer, Estim=electrical stimulation.
* Studies that compared 2 types of interventions within the same category.

(n=236 participants)[34–42] used some form of resistance training as the primary intervention. PEDro scores for the studies in this category ranged from 3 to 8, with an overall average rating of 5.7 and a median of 6. Of the 9 studies included in this category, 5 (56%) were rated good,[36,37,39,41,42] 3 (33%) were rated fair,[34,35,40] and 1 was rated poor.[38] The mean change in self-selected gait speed for this category ranged from 0.01 to 0.20 m/s, with effect sizes ranging from −0.28 to 0.95. Out of the 9 resistance training articles, 3 (33%) met the MCID,[34–36] 3 (33%) met within-group statistical significance,[34–36] and 1 (11%) met between-groups statistical significance for self-selected speed[34] (Tab. 2).

The age range of participants in the resistance training studies was approximately 4 to 21 years. Types of resistance training included traditional strength training,[34,38,42] functional strength training,[34,35,39–41] velocity training,[36] and circuit training.[37] Interventions used for resistance training included isokinetic dynamometry,[34,36,38] resistance devices (free weights, cuff weights, resistance bands, weight machines),[34,37,42] and body weight during functional activities, such as sit-to-stand transfers, step-ups, and squats.[34,35,39–41] Participants trained between 1 and 3 times per week for between 4 and 12 weeks for a total of 8 to 36 sessions. Volume ranged from 1 to 6 sets per exercise and from 5 to 12 repetitions. Intensity ranged from 20% one-repetition maximum (1RM) to 100% 1RM or maximum effort. Body weight was often reported as the intensity with the percentage of 1RM unknown (Tab. 1).

Miscellaneous. For this systematic literature review, there were 7 studies (29%) (n=207 participants) in the miscellaneous category.[43–49] Three (43%) of the studies used electrical stimulation as the intervention.[43,44,47] The remaining 4 studies (57%) included different interventions, such as electromyographic (EMG) biofeedback,[45] stationary cycling,[46] whole-body vibration,[48] and enhanced sensory input during a resisted functional activity.[49]

Three studies of 3 different electric stimulation protocols had PEDro scores ranging from 5 to 7, with an average and median of 6.[43,44,47] One study was rated fair,[47] and 2 studies were rated good.[43,44] The mean change in gait speed for these studies ranged from 0.05 to 0.17 m/s, with effect sizes of 0.00, 0.12, and 1.96. One of the studies exceeded the MCID and reported within-group and between-groups statistical significance (Tab. 2).[47] Children in the electrical stimulation studies (n=46) ranged from 5 to 14 years of age. Interventions included neuromuscular electrical stimulation (NMES) of the quadriceps and tibialis anterior muscles,[47] electrical stimulation of the gluteus maximus muscle,[43] and cyclical NMES (duty cycle=6 seconds “on,” 10–14 seconds “off”), followed by functional electrical stimulation of the quadriceps and dorsiflexor muscles during gait.[44] Frequency and duration ranged from 4 to 5 times per week for 4 weeks to 6 to 7 times per week for 10 weeks. The length of each session ranged from 20 to 30 minutes to 1 hour (Tab. 1).

PEDro scores for the 4 remaining miscellaneous articles ranged from 6 to 8.[45,46,48,49] Two of these studies met or exceeded MCID and reported within-group and between-groups statistical significance for the interventions of EMG biofeedback during anterior tibialis muscle strengthening and triceps surae muscle relaxation[45] and whole-body vibration.[48] See Tables 1 and 2 for details of these studies.

Meta-analysis

Random-effects meta-analyses were conducted to quantify the overall effect of gait training (n=201) and resistance training (n=236) on gait speed and to begin to make comparisons between these 2 types of interventions. The majority of studies (21/24, 88%) compared the intervention category with either no treatment or traditional physical therapy. For gait training (with and without body-weight support), the overall Hedges’ g was 0.92 (95% CI=0.19, 1.66), which was statistically significant (Z=2.45, P=.01) (Fig. 2). When the 2 interventions that compared 2 different types of gait training were removed from the analysis,[20,33] the Hedges’ g was 0.75 (95% CI=0.15, 1.36), which remained statistically significant (Z=2.44, P=.02). For resistance training, the overall Hedges’ g was 0.06 (95% CI=−0.12, 0.25), which was not statistically significant (Z=0.66, P=.51) (Fig. 3). When one intervention that compared 2 different types of resistance training was removed from the analysis,[36] the Hedges’ g was similar (0.058; 95% CI=−0.15, 0.27; Z=0.54, P=.59). Heterogeneity analysis revealed homogeneity of variance among studies in the gait training (I^2=8.84%, Q7=7.68, P>.05) and resistance training (I^2=0%, Q8=8.03, P>.05) categories. Because the between-studies variance was homogenous within categories, we can conclude that the effect was robust across the studies included in the meta-analysis and that summary statistics can be used to interpret results.

Discussion

Categories of Intervention

Gait training. The results of the meta-analysis revealed that the overall effect of gait training on gait speed was large, with a standardized effect size of 0.92. This is an important addition to the body of knowledge regarding gait training for children with CP. Previous systematic reviews have not included a meta-analysis.[16,17] Damiano and DeJong[17] included effect sizes, but only 3 studies in their systematic review provided enough data for the calculations. Furthermore, these previous review articles focused on treadmill training rather than all types of gait training.

Gait training studies reviewed varied by type of training (overground versus treadmill), comparison intervention, functional walking level of study population, and amount of body-weight support given during the training (Tab. 1, gait training). However, some general conclusions can be made from the literature. It would appear that based on review of between-groups differences, effect size, PEDro score, and MCID, gait training without body-weight support (pedometer-based overground training, treadmill training without body-weight support, and instrumented feedback treadmill training)[19,20,32] was more effec-

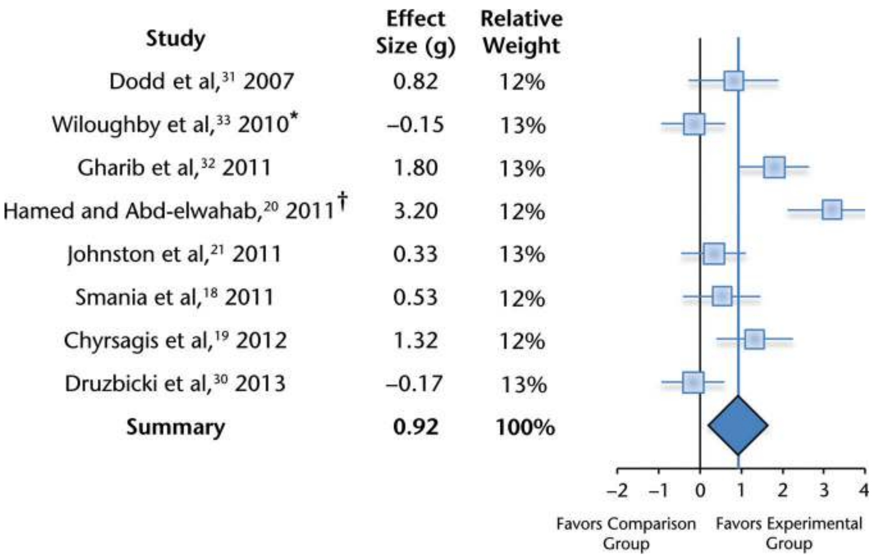

Figure 2.
Forest plot of standardized effect sizes (Hedges' g) and 95% confidence intervals (represented by error bars) for effects of gait training on gait speed. Overall effect size (g)=0.92; 95% confidence interval=0.19, 1.66; Z=2.45; P=.014. * Partial body-weight–supported treadmill training (experimental) vs overground walking (control). † Gait training with pedometer (experimental) vs gait training without pedometer (control). The relative weight of each study is illustrated by the size of the square symbol.

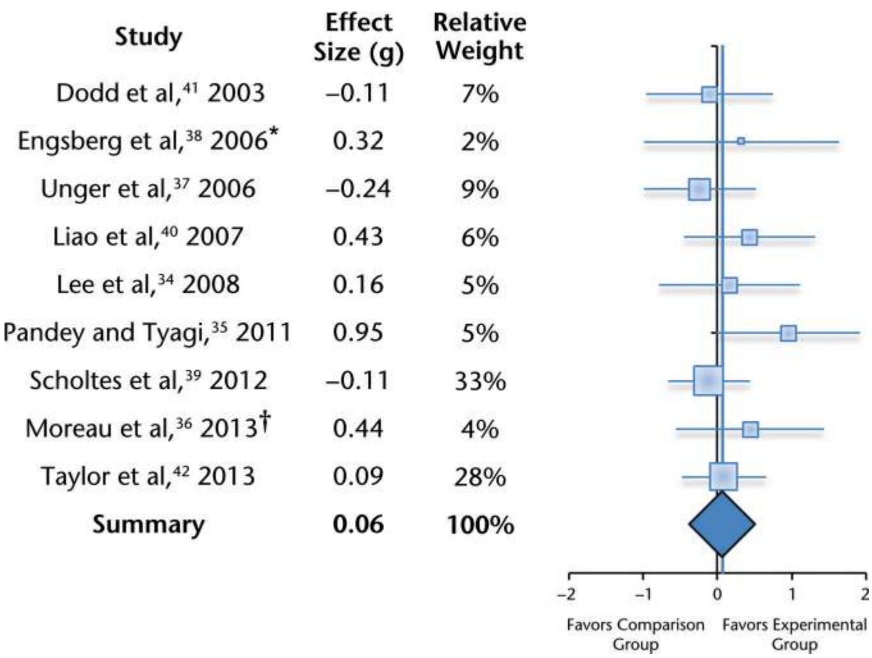

Figure 3.
Forest plot of standardized effect sizes (Hedges' g) and 95% confidence intervals (represented by error bars) for effects of resistance training on gait speed. Overall effect size (g)=0.06; 95% confidence interval=–0.12, 0.25; Z=0.66; P=.51. * Combined treatment groups; data pooled. † Velocity training (experimental) vs strength training (control). The relative weight of each study is illustrated by the size of the square symbol.

tive than gait training with body-weight support.[18,21,30,31,33] Effect sizes for gait training with body-weight support (−0.17 to 0.82) were lower than those for gait training without body-weight support (1.32–3.20). However, 2 of the 3 studies that trained without body-weight support enrolled only children with hemiplegia.[20,32] In contrast, the studies that used body-weight support enrolled children with spastic diplegia or quadriplegia who either ambulated independently or used assistive devices, such as crutches, walkers, and gait trainers, and reported lower frequency and duration of intervention overall.[18,21,30,31,33] Therefore, the effect of gait training relative to body-weight support across functional walking levels (Gross Motor Function Classification System [GMFCS] levels, hemiplegia/diplegia) remains unclear.

Overground gait training with a "talking" pedometer in addition to traditional physical therapy in children with hemiplegia produced the largest mean change in gait speed (mean change=0.26 m/s), within-group and between-groups significant differences, and effect size for gait speed (Hedges' g=3.20).[20] However, the comparison group that received overground gait training with traditional physical therapy also had significant improvements in gait speed. Therefore, this study highlights the additive effects of pedometer use as an adjunctive therapy with overground gait training. Similarly, gait training was augmented by auditory and visual feedback in the study by Gharib et al,[32] resulting in significant between-groups changes in gait speed. Thus, augmented feedback during gait training without body-weight support ("talking" pedometer, auditory and visual cues)[20,32] may have increased participation, resulting in greater improvements in gait speed than observed with gait training alone.

To date, there are no published dosing guidelines for the use of gait training to enhance gait speed in people with CP. Future work should focus on determining optimal dosing parameters to establish type, frequency, intensity, duration, and volume of treadmill training to guide individualized prescription by age and functional level (GMFCS, hemiplegia/

diplegia) in children with ambulatory CP. Once optimal dosing parameters are determined, further testing in longitudinal cohort or population-based cross-sectional research would be essential to understand the timing of focused intensive gait training relative to the evolving walking activity of children with CP during maturation.

This body of literature for gait training presented several limitations, which influence the translation of the results to clinical practice. Limitations include inconsistent amount of body-weight support provided and potentially insufficient duration, intensity, and total volume of gait training, which may have negatively biased the results.

Resistance training. Resistance training refers to all types of resistance exercise, such as strength training, power training, and plyometrics, among others. A systematic literature review of RCTs by Scianni et al[15] and follow-up to their review by Verschuren et al[50] concluded that despite moderate increases in strength, there was no evidence that strength training (the most widely used form of resistance training in CP) improved walking ability or overall function in ambulatory children with CP. Scianni et al[15] reported that the overall effect of strengthening interventions compared with no intervention was to increase gait speed by 0.02 m/s, which is considered to be clinically insignificant. Our meta-analysis and systematic literature review adds to this body of literature by including several RCTs that have been published since the study by Scianni et al[15] and by providing change scores that can be compared with an MCID for gait speed in this population in addition to statistical significance and standardized effect sizes. Our meta-analysis results revealed that the overall effect of resistance training on gait speed was not statistically significant, with a standardized effect size of 0.06, which is considered trivial. However, it is important to discuss pertinent studies, which may shed some light on these findings.

The National Strength and Conditioning Association's published guidelines for resistance training for youth are the current clinical recommendations for resistance training for youth with CP.[51] Verschuren et al[50] reported that several RCTs on strength training specifically in CP did not follow the recommended guidelines for intensity (load or percentage of 1RM) and duration. Recommendations for intensity are 85% of 1RM delivered at a frequency of 2 to 3 times per week for a duration of at least 8 weeks. The lower doses reported in these studies may explain less favorable results. However, 2 recently published good-quality RCTs adhered to all of the recommended dosing guidelines and sought to answer the question of whether strength training could result in increases in walking ability in children with CP.[39,42] One of these 2 studies used isotonic exercises using weight machines, and the other study used functional strength training activities (see Tab. 1 for study details). Yet, these adequately powered studies failed to show an effect of strength training on walking ability, including gait speed.

Another RCT of good quality compared velocity training, a type of training for muscle power, with traditional strength training of the quadriceps muscle using an isokinetic dynamometer.[36] The velocity training group showed significant increases in gait speed that met or exceeded the MCID and approached a medium effect size for self-selected and fast gait speeds when compared with strength training. Strength training did not result in changes in gait speed, further confirming the results of other higher-quality RCTs.[39,42]

Two of the 9 studies reported mean changes in gait speed for the experimental group that exceeded the MCID and showed either within-group or between-groups statistical significance compared with conventional physical therapy or no intervention.[34,35] Lee et al[34] trained multiple muscle groups utilizing a combination of functional strength training and isotonic and isokinetic exercises, and Pandey and Tyagi[35] investigated functional strength training. However, the quality of the studies was fair. Pandey and Tyagi did not report sufficient information on dosing parameters to properly evaluate or replicate this study. In addition, the duration of both studies was less than the recommended guideline of a minimum of 8 weeks.

The inclusion of higher-quality RCTs in this meta-analysis and systematic literature review provides additional evidence to determine the effects of resistance training on gait speed. The results of the meta-analysis suggest that strength training in CP, regardless of the type and devices used, even when properly dosed according to the recommended guidelines, does not result in clinically meaningful changes in gait speed. However, preliminary work on resistance training for muscle power, such as velocity training,[36] was shown to be an effective means of increasing gait speed compared with traditional strength training in a good-quality, individual study and should be investigated further.

Miscellaneous. The studies discussed in this section were not included in the meta-analysis because of the limited number of articles for each intervention type; however, systematic review of these articles provides important insight. Only 1 (33%) of 3 studies that evaluated the effects of electrical stimulation on gait speed met or exceeded the MCID and showed statistically significant changes in gait speed in the experimental group. However, this was a lower-quality study, rated as fair, with a small sample size and may not be reproducible due to the lack of methodological detail provided in the article.[47] Of the remaining 4 studies in the miscellaneous category, 2 (50%) reported significant increases in gait speed that exceeded the MCID, with large effect sizes. Dursun et al[45] used EMG biofeedback during anterior tibialis muscle strengthening and triceps surae muscle relaxation. Lee and Chon[48] administered whole-body vibration training with participants in a standing position. Both studies were rated good on the PEDro scale and either targeted or had subsequent effects on the anterior tibialis muscle. The experimental group in both of these studies received the experimental intervention in addition to their conventional physical therapy, so the total intervention time per session was higher for the experimental group.[45,48] This approach may have biased the results in favor of the experimental group.

In summary, preliminary work on EMG biofeedback training of the ankle[45] and vibration training in standing[48] were shown to be effective in increasing gait speed in individual, good-quality studies and may warrant further investigation. Evidence to support the effectiveness of electrical stimulation[43,44,47] for improving gait speed is limited.

Limitations

We reported on only one outcome measure (gait speed) for comparison across interventions. However, gait speed is the most widely used outcome measure of walking ability and is consistent with the purpose of the systematic review. Other measures of activity may be more useful in determining the overall clinical effectiveness of these interventions on walking ability. Evidence for the effects of these interventions on participation is limited in the literature and should be explored in future studies. Another limitation is that this review did not address follow-up or retention of gains in gait speed. Future research and publications addressing this question should consistently report change scores and standard deviations (or CIs) of the change scores to allow for the most accurate effect size calculations and interpretation. Finally, participant blinding and therapist blinding are almost impossible in the majority of rehabilitation trials, rendering a PEDro score of 8 the highest score that could be obtained in this review.

In conclusion, this systematic review of the effectiveness of interventions to improve gait speed in children with CP used a 4-tier approach in evaluating the literature. This review adds to the body of knowledge by investigating: (1) the relationship of the outcome to the MCID, an important measure of clinical significance; (2) within-group statistical significance; (3) between-groups statistical significance; and (4) effect sizes for between-groups differences with meta-analysis. This review also expands our understanding of the effectiveness of interventions by comparing and contrasting the effect of different interventions on the outcome measure of gait speed using standardized metrics.

The results of the meta-analysis suggest that interventions focused on gait training were the most effective in improving gait speed for children with CP. In contrast, strength training, a type of resistance training, even if properly dosed, was not shown to be effective in improving gait speed. Based on the systematic literature review, including the analysis of MCIDs, statistical significance, effect sizes, and study quality, we can conclude that task specificity and auditory and visual feedback appear to be important factors for improving gait speed, regardless of whether gait training is performed on a treadmill or overground, with or without body-weight support. Velocity training of the quadriceps muscles, EMG biofeedback training of the anterior tibialis muscle, and whole-body vibration also were shown to improve gait speed in ambulatory children with CP in good-quality, individual studies and warrant further investigation.

Future research should focus on establishing optimal dosing parameters for frequency, intensity, duration, and volume of training for these types of interventions for improving gait speed. These guidelines could be used for individualized treatment prescription, thus informing clinical practice. Given the evolving walking activity of children with CP through the lifespan, the timing of such training should also be examined further in order to optimize effort, time, and fiscal resources.

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