Exercise interventions improve postural control in children with cerebral palsy: a systematic review

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ABBREVIATIONS

AACPDM	American Academy of Cerebral Palsy and Developmental Medicine
BF&S	Body functions and structures
F-BWS	Full body weight support
FES	Functional electrical stimulation
ICF	International Classification of Functioning, Disability and Health
NDT	Neurodevelopmental therapy
No-BWS	No body weight support
P-BWS	Partial body weight support
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

AIM The aim of this study was to evaluate the efficacy and effectiveness of exercise interventions that may improve postural control in children with cerebral palsy (CP).
METHOD A systematic review was performed using American Academy of Cerebral Palsy and Developmental Medicine (AACPDM) and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. Six databases were searched using the following keywords: ('cerebral palsy' OR 'brain injury'); AND ('postur*' OR 'balance' OR 'postural balance' [MeSH]); AND ('intervention' OR 'therapy' OR 'exercise' OR 'treatment'). Articles were evaluated based on their level of evidence and conduct.
RESULTS Searches yielded 45 studies reporting 13 exercise interventions with postural control outcomes for children with CP. Five interventions were supported by a moderate level of evidence: gross motor task training, hippotherapy, treadmill training with no body weight support (no-BWS), trunk-targeted training, and reactive balance training. Six of the interventions had weak or conflicting evidence: functional electrical stimulation (FES), hippotherapy simulators, neurodevelopmental therapy (NDT), treadmill training with body weight support, virtual reality, and visual biofeedback. Progressive resistance exercise was an ineffective intervention, and upper limb interventions lacked high-level evidence.
INTERPRETATION The use of exercise-based treatments to improve postural control in children with CP has increased significantly in the last decade. Improved study design provides more clarity regarding broad treatment efficacy. Research is required to establish links between postural control impairments, treatment options, and outcome measures. Low-burden, low-cost, child-engaging, and mainstream interventions also need to be explored.

Cerebral palsy (CP) is the most common cause of physical disability in childhood, with an estimated incidence of 2.11 per 1000 live births.[1] Central to the definition and diagnosis of CP is impaired development of movement and posture.[2] Postural control dysfunction derives from primary brain injury, which causes deficits in postural networks. Motor (producing) networks are impacted by deficits such as muscle spasticity, contracture, decreased isometric force production and abnormal timing, and reduced amplitude of muscle recruitment. Perceptual (orienting) networks are impacted by deficits including poor registration and/or perception in visual, tactile, proprioceptive, and vestibular systems.[3] Individually and collectively, these factors can result in problems with balance and/or orientation in children with CP. To date, it is known that children with CP show deficits in anticipatory postural adjustments,[4–9] and reactive postural adjustments,[10–12] as well as sensory[4,13] and musculoskeletal components[14,15] of postural control, compared with children with typical development. This dysfunction is known to contribute to limitations in gross motor skills that require balance,[16] especially gait,[17,18] during upper limb activities such as reaching,[19] and during oral motor activities such as eating, swallowing, and speaking.[20] These limitations restrict participation across a broad range of life domains, including self-care, education, and recreation.[21] Despite the significant impact that postural control dysfunction has on the activity and participation of children with CP, and indeed their caregivers, optimal interventions for this core deficit are not well understood. While children with CP receive or participate in a wide range of passive or active interventions aimed to improve movement and posture, often the specific impact on postural control is not well measured or documented. This systematic review seeks to examine reported exercise interventions for children with CP, to critique their efficacy and effectiveness for postural control outcomes, and to make recommendations for improved therapeutic management of this fundamental attribute of CP.

Postural control can be defined as the ability to control the body's position in space for the purposes of stability and orientation.[22,23] Postural stability, or balance, is the ability to maintain and/or regain the centre of

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mass within the base of support where gravity is the key vector.[22,24] Stability tasks can be considered static, when the body is stationary (e.g. when sitting or standing on a stable surface), or dynamic, when the body is moving, either during self-initiated internal perturbations (e.g. walking), or in response to external perturbations initiated by other people or objects (e.g. being pushed, or maintaining a stance on a moving bus).[25] Postural orientation is the ability to attain and maintain an optimal functional relationship between body segments, a task, and the environment (e.g. for writing, reaching, or looking).[22,24]

The effect and intent of postural control interventions need to be evaluated with reference to a framework of core postural control elements. Although numerous theoretical frameworks exist, the contemporary Systems Control Theory is the most comprehensive for this purpose.[22,26,27] This theory describes postural control as a complex interaction between seven components: (1) neuromuscular synergies; (2) internal representations; (3) adaptive mechanisms (including reactive postural adjustments); (4) anticipatory mechanisms (including anticipatory postural adjustments); (5) sensory strategies; (6) individual sensory systems; and (7) musculoskeletal components.[22] Children with motor disorders can show deficits in one or more of these components. Similarly, interventions and outcomes can target one or more components.

A burst of postural control intervention research in the 1980s and 1990s, relating to children with CP, prompted the publication of three review articles.[28–30] First of all, Campbell[28] published a non-systematic review of interventions for children with CP. This review proposed preliminary support for the following postural control interventions: gait training with real-time auditory biofeedback or retrospective verbal feedback; neurodevelopmental therapy (NDT); therapeutic horseback riding; and inhibitory casting. A decade later, Westcott and Burtner[29] presented a second, non-systematic review of children with motor disabilities (including CP) using the systems control approach. This review supported Campbell's findings, and also supported some new interventions, including reactive balance training using platform perturbations and anticipatory balance training with computer feedback. There was insufficient or conflicting evidence regarding outcomes of interventions targeting musculoskeletal (strengthening), sensory (vestibular stimulation), and motor (electrical stimulation) processes.[29] To improve the existing body of research, the authors recommended that further studies include (1) outcome measures for both postural control and motor function; (2) more task-specific training to improve functional outcomes; and (3) evaluation of mainstream recreational activities for their potential impact on postural control. In 2005, the first systematic review of postural control interventions for children with CP was published by Harris and Roxborough.[30] The authors supported Campbell's[28] view that progress in study quality and methodological rigor is required to provide adequate clinical guidance.

What this paper adds

- First systematic review of postural control exercise interventions for children with cerebral palsy.
- Exercise interventions that improve postural control have increased in the last decade.
- Improved study design has clarified efficacy of postural control exercise approaches.
- Five exercise interventions reached moderate evidence level, however, no interventions were rated strong.

The outcomes and recommendations of these reviews prompted the study of many new clinical and mainstream approaches to treating postural control dysfunction in children with CP. Key examples include hippotherapy, treadmill training, upper limb therapy, strength training, and virtual reality technologies. However, it has been almost 10 years since the last review of postural control interventions in children with CP; therefore, an updated systematic review, to evaluate the efficacy and effectiveness of traditional and contemporary exercise interventions, is needed. In this respect, efficacy is defined as the ability of an intervention to improve postural control under ideal conditions, such as in a laboratory, and effectiveness is defined as the ability of an intervention to provide benefits during usual conditions of clinical care.[31,32] Therefore, the aim of this paper is to present a systematic review of exercise interventions reported for use in children with CP; to evaluate the efficacy and effectiveness of these interventions for postural control outcomes, according to international standards; and to recommend appropriate management of postural control dysfunction in children with CP.

METHOD

This systematic review was conducted according to principles of American Academy of Cerebral Palsy and Developmental Medicine (AACPDM) methodology for developing systematic reviews of treatment interventions,[33] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[34–36] The study did not require human participation; therefore, ethical approval was not required.

Search strategy

A systematic literature search of articles published between January 1980 and December 2013 was performed using the following electronic databases: PubMed, EMBASE, EBSCOhost (MEDLINE and CINAHL), the Cochrane Library, and PEDro. Search terms were designed to include the population of interest ('cerebral palsy' OR 'brain injury'), and intervention type ('postur*' OR 'balance' OR 'postural balance' [MeSH]), AND ('intervention' OR 'therapy' OR 'exercise' OR 'treatment'). Secondary searches included reference list checking of the included articles, electronic searches for included interventions by name and author, and citation tracking of all included articles. Two authors (RD and LJ or SL) examined the titles and abstracts of the articles identified by these searches. Full-text articles were retrieved if they fulfilled inclusion criteria, or if further clarification regarding the fulfilment of inclusion criteria was required. If agreement on inclusion could not be reached following review by two of the authors, the third author (LJ or SL) was consulted.

Inclusion and exclusion criteria

Articles were included if (1) they were full articles, published in English, in peer-reviewed journals, after 1980; (2) study participants were children diagnosed with CP, and aged between 0 and 18 years; (3) they performed a land-based exercise intervention that required active participation by the child; and (4) they reported the efficacy or effectiveness of the intervention, for improving postural control, using at least one outcome measure of either postural stability (static or dynamic balance), or postural orientation (e.g. postural alignment). Articles were excluded if they were non-systematic reviews or opinion articles, or if they reported (1) passive interventions (e.g. orthotics, equipment such as seating, or support garments); (2) water-based interventions; (3) medical or surgical interventions; or (4) active exercise interventions without any reported outcome measures for postural control.

Data extraction and quality appraisal

Two authors gathered data from each article using the appropriate AACPDM 'study data extraction summary form'; the forms used were relevant for either group or single-subject research study designs. The forms recorded information regarding participants, intervention(s), outcome measure(s) (for postural control or other motor outcomes), results, and potential adverse effects. The quality of each included article was assessed in two steps: (1) by assignment of the level of evidence (for all studies); and then (2) by evaluation of conduct (for studies with level I–III evidence only [as determined using guidelines for each study type recommended by the AACPDM]). Group research designs were assigned levels of evidence using the classification described by Sackett et al.[37] (see Table SI, online supporting information), where level I studies are most able to demonstrate that the intervention was responsible for the reported outcome. Conduct of level I to III group studies was rated using a seven-item questionnaire, with studies scoring 'yes' on six or seven items rated as strong, on four or five items rated as moderate, and on three or less items rated as weak. Single-subject research design studies were assigned levels of evidence using the classification described by Logan et al.[38] (see Table SI). Conduct of level I to III single-subject research design studies was rated using a 14-item questionnaire, with studies scoring 'yes' on between 11 and 14 items rated as strong, on 7 to 10 items rated as moderate, and on seven or less items rated as weak. Systematic review studies were rated using the classification of Sackett et al.[37] Conduct of systematic reviews was evaluated using Oxam and Guyatt's[39] classification, which yields a score out of 10.

RESULTS

A total of 911 articles were identified, 890 from initial searches, and 21 from secondary searches. After duplicates were removed, the titles and abstracts of 558 articles were screened. Of these, 154 full-text articles met initial criteria and were retrieved for review, with 45 studies meeting final inclusion criteria. The flow of studies, and reasons for exclusion at each stage, is summarized in a PRISMA diagram (Fig. 1).

From the 45 included articles (evidence levels I–V), 13 intervention types were identified that purported to impact postural stability or postural orientation in children with CP: functional electrical stimulation (FES) (n=2); gross motor task training (n=4); hippotherapy (n=9); hippotherapy simulators (n=3); progressive resistance exercise (n=1); reactive balance training (n=3); treadmill training with no body weight support (no-BWS) (n=1); treadmill training with partial or full body weight support (P-BWS or F-BWS respectively; n=5); trunk-targeted training (n=2); upper limb interventions (n=2); visual biofeedback (n=1); and virtual reality (n=8). Within the included articles, NDT was used as a comparison treatment in seven (n=7, not adding to the study tally), and appeared in one other where it was used as the sole intervention (n=1). Finally, three systematic reviews were identified, including one discussing postural control interventions in general, and two specifically discussing hippotherapy.

Results were tabulated based on AACPDM guidelines. Articles that were rated as level I to III (n=22) met criteria for full evaluation, which is provided in Table I, including citation, design, evidence level and conduct rating, intervention type, participants, results, outcome measures, and coding (according to the International Classification of Functioning, Disability and Health [ICF]: Children & Youth Version,[40] and postural control component according to Systems Control Theory). Tables SIIa,b (online supporting information) provide additional information regarding participant characteristics and intervention methodology for each study (level IV–V studies were also included in this table to comprehensively describe the scope of research available for each intervention type). Tables SIIIa,b,c (online supporting information) report the objective conduct item scores for level I to III studies with group, single-subject, and systematic review designs. Table SIV (online supporting information) documents reported adverse events.

In the following sections, each intervention type with available level I to III evidence is critiqued for (1) the overall strength of the evidence presented; (2) the efficacy and/or effectiveness for improving postural control when considering each component ('body functions and structures' (BF&S), 'activity', and 'participation') of the ICF; (3) links between outcomes across the ICF; and (4) adverse events, if reported. Intervention types are discussed in alphabetical order.

Functional electrical stimulation

Two studies,[41,42] both evidence level II (Table I), applied FES to abdominal and lumbar muscles simultaneously, with

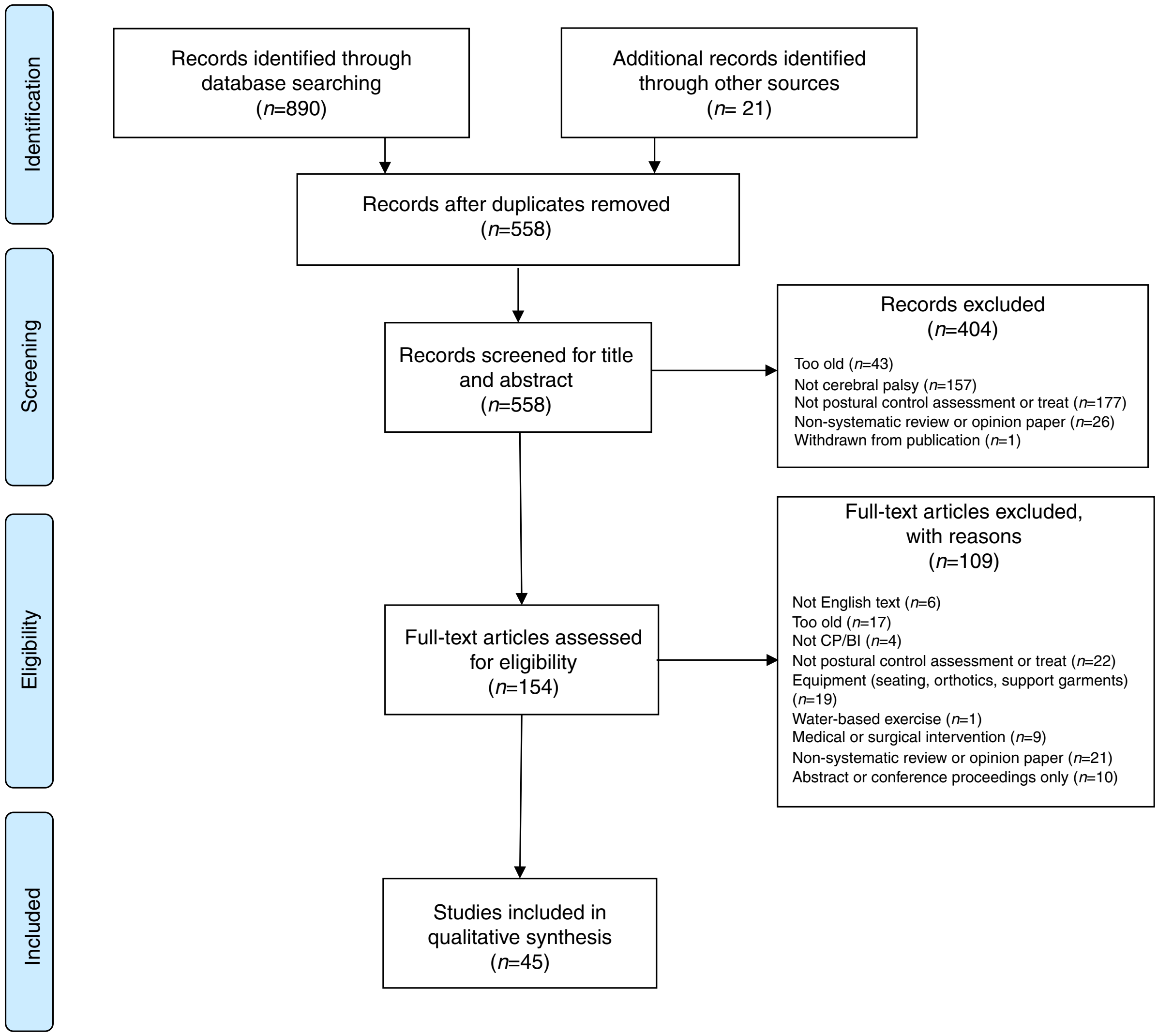

Figure 1: PRISMA flow diagram.

the aim of improving muscle strength and function. Both studies used the following FES parameters with a sequence of 10 seconds ‘on’ followed by 12 seconds ‘off’: intensity of 20 to 30mA; pulse width of 250μs; and frequency of 25 to 35Hz. Both studies used the same dosage of 10 to 18 hours (five or six 30min sessions/wk for 4–6wks), together with rehabilitation (stretching, strengthening, and mobility activities, and Bobath treatments of inpatients in rehabilitation hospitals) for children aged between 1 and 10 years with spastic diplegia (Gross Motor Function Classification System [GMFCS] Level not reported). FES, along with rehabilitation, improved postural alignment (BF&S) to a greater extent than rehabilitation alone (evidence level II, conduct weak; see Table SIIIa).[41,42] No discomfort was reported by children receiving FES (see Table SIV).[42]

Gross motor task training

Gross motor task training involves repetition of simple functional gross motor exercises (e.g. sit-to-stand exercises, step-ups, walking and standing activities, and reaching to limits of stability). Of four studies, two were level II (Table I). Improvement was reported for the ‘activity’, but not the BF&S, component. Thirty hours (five 1h sessions/wk for 6wks) of sit-to-stand and step-up exercises improved standing balance (‘activity’) and dynamic postural stability during gait (‘activity’) in children with CP aged between 5 and 12 years (evidence level II, conduct moderate; see Table SIIIa).[43] A lower dose of 10 hours (two 1h sessions/wk for 5wks) of walking, standing, sit-to-stand, and object pick-up activities improved dynamic balance during gait (‘activity’) in 4- to 11-year-old children with CP (evidence level II, conduct moderate; see online Table SIIIa).[44]

Hippotherapy

Hippotherapy is the provision of sensory and motor input via the movements of a horse, with programmes designed by professionals with hippotherapy qualifications.[53] From 11 studies, three level II or III studies, and two systematic

Table I: Summary of level I to III included studies

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
Functional electrical stimulation (FES)							
Park et al.[41]	Group, II, Weak	FES	CP (spastic diplegic); mean age=13y 6mo; n=26	Improved postural symmetry in sitting (Cobb and kyphotic angle, $p<0.05$); no change in lumbosacral angle	Radiographic measures: Cobb, kyphotic, and lumbosacral angle	B (b7101)	MSk
				Improved sitting function ($p<0.05$)	GMFM: B (sitting)	A (d410–d429, d455)	APA, IR, MSk
Karabay et al.[42]	Group, II, Weak	FES	CP (spastic diplegic); 2–10y; n=33	Improved postural symmetry in sitting (Cobb, kyphotic, and sacral angle, $p<0.001$)	Radiographic measures: Cobb, kyphotic, and sacral angle	B (b7101)	MSk
				Improved sitting ($p<0.05$)	GMFM: B (sitting)	A (d410–d429, d455)	APA, IR, MSk
Gross motor task training							
Katz-Leurer et al.[43]	Group, II, Moderate	Gross motor task training	TBI and CP; GMFCS I–II; 5–13y; n=20	No change in strength	Muscle strength of lower limb (dynamometry)	B (b7300)	MSk
				No change in walking performance	Walking speed over 10m	B (b770)	APA, IR, MSk
				No change in walking efficiency	Walking energy expenditure index	B (b455)	APA, IR, MSk
				Improved dynamic balance in standing ($p<0.01$) and walking ($p<0.01$)	Functional reach test	A (d4105, d4106, d4452)	APA, IR
					Timed-up and go test	A (d4103, d4104, d4500)	APA, MSk
Salem and Godwin.[44]	Group, II, Moderate	Gross motor task training	CP; GMFCS I–III; 4–11y; n=10	Improved gross motor function: standing (p=0.009) and walking, running, and jumping (p=0.017)	GMFM-88: D (standing) and E (walking, running, and jumping)	A (d410–d429, d455)	APA, IR, MSk
				Improved dynamic balance: walking (p=0.017)	Timed-up and go test	A (d4103, d4104, d4500)	APA, MSk
Hippotherapy							
Kang et al.[45]	Group, II, Weak	Hippotherapy	CP (hemi- and diplegic ambulatory); 6–10y; n=45	Improved sitting balance ($p<0.05$)	Stabilometry (sitting): pathway and velocity of COP while sitting still for 30s with visual fixation	B (b755)	IR, sensory, MSk
Hamill et al.[46]	SSRD, III, Moderate	Hippotherapy	CP; GMFCS V; 27–54mo; sitting; n=3	No change in sitting postural control	Sitting Assessment Scale	A (d4153, d4300, d440) and B (b760)	IR, APA, MSk
				No change in gross motor function overall, or in sitting	GMFM-88: B (sitting) and total score	A (d410–d429, d455)	APA, IR, MSk

Table I: Continued

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
Kwon et al.[47]	Group, III, Moderate	Hippotherapy	CP; GMFCS I–II; 4–10y; *n*=32	Improved walking (stride length [*p*<0.001] and walking speed [*p*=0.002]); no change in cadence, single limb support, or pelvic and hip kinematics	Temporal–spatial and kinematic gait parameters	B (b770, b710)	APA, MSk
				Improved overall gross motor function (*p*=0.003); improved walking, running, and jumping (*p*=0.042)	GMFM-66/88: E and total score	A (d410–d429, d455)	APA, IR, MSk
				Improved balance in standing (*p*=0.004)	Paediatric Balance Scale	A (d4103, d4104–d4106, d4153-d4154, d4200, d4452)	APA, IR, sensory, MSk
Hippotherapy simulator							
Borges et al.[48]	Group, II, Weak	Hippotherapy simulator	CP (spastic diplegic); GMFCS II–IV; 3–12y; *n*=40	Improved postural control in sitting (AP, *p*=0.0001; ML, *p*=0.0069)	Stabilometry: voluntary COP movement in sitting	B (b760)	APA
				No change in motor classification	GMFCS	A (d450–d469)	APA, IR, MSk
Herrero et al.[49]	Group, II, Strong	Hippotherapy simulator	CP; GMFCS I–IV; 4–18y; *n*=38	No change in sitting postural control	Sitting Assessment Scale	A (d4153, d4300, d440)and B (b760)	APA, IR, MSk
				Improved sitting function (odds ratio=3.9; 95% CI=0.68–22.7); no change in overall gross motor function	GMFM-66: B (sitting) and total score	A (d410–d429, d455)	APA, IR, MSk
NDT							
Park et al.[41]	Group, II, Weak	NDT	CP (spastic diplegia); 8–16mo; *n*=26	Improved postural symmetry in sitting (Cobb angle only *p*<0.05); no change in kyphotic and lumbosacral angle	Radiographic measures: Cobb, kyphotic, and lumbosacral angle	B (b7101)	MSk
				Improved sitting function (*p*<0.05)	GMFM: B (sitting)	A (d410–d429, d455)	APA, IR, MSk
Salem and Godwin[44]	Group, II, Moderate	NDT	CP (quadriplegic and diplegic); GMFCS I–III; 4–11y; *n*=10	Improved gross motor function: standing and walking, running, and jumping (no *p*-value reported)	GMFM-88: D (standing) and E (walking, running, and jumping)	A (d410–d429, d455)	APA, IR, MSk
				Improved dynamic balance: walking (no *p*-value reported)	Timed-up and go test	A (d4103, d4104, d4500)	APA, MSk
Borges et al.[48]	Group, II, Weak	NDT	CP (spastic diplegia); GMFCS II–V; 3–10y; *n*=40	Improved postural control: sitting (AP and ML, no *p*-value reported)	Stabilometry: voluntary COP movement in sitting	B (b760)	APA
				No change in motor classification	GMFCS	A (d450–d469)	APA, IR, MSk
Karabay et al.[42]	Group, II, Weak	NDT + conventional PT	CP (spastic diplegic); 2–10y; *n*=33	Improved postural symmetry: sitting (Cobb, kyphotic angle [*p*<0.001] and sacral angel [*p*<0.003])	Radiographic measures: Cobb, kyphotic, and sacral angle	B (b7101)	MSk
				Improved sitting (*p*<0.001)	GMFM: B (sitting)	A (d410–d429, d455)	APA, IR, MSk

Table I: Continued

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
El-Shamy et al.[50]	Group, II, Moderate	NDT	CP (spastic diplegic); GMFCS I–II; 10–12y; $n=30$	Improved limits of stability ($p<0.001$)	Biodex, DSL level 12: movement of COP with visual feedback	B (b760)	APA, IR, sensory
				Improved (reduced) falls risk ($p<0.05$)	Biodex: COP pathway in response to perturbation calculation of falls risk	A (d450)	RPA, NMR
				Improved functional standing balance ($p<0.05$)	Paediatric Balance Scale	A (d4103, d4104–d4106, d4153-d4154, d4200, d4452	APA, IR sensory, MSk
Kwon et al.[47]	Group, III, Moderate	NDT	CP (bilateral spastic); GMFCS I–II; 4–10y; $n=32$	Improved walking (cadence $p=0.013$; walking speed $p=0.002$); no change in stride length, single limb support, or pelvic and hip kinematics	Temporal–spatial and kinematic gait parameters	B (B770,B710)	APA, MSk
				No change in gross motor function	GMFM-66/88: E and total score	A (d410–d429, d455)	APA, IR, MSk
				No change in standing balance	Paediatric Balance Scale	A (d4103, d4104–d4106, d4153–d4154, d4200, d4452)	APA, IR, sensory, MSk
Progressive resistance exercises							
Bandholm et al.[51]	Group, II, Strong	Progressive resistance training	CP; GMFCS I; 5–14y; $n=15$	Improved plantar flexion MVT only ($p<0.035$)	Ankle muscle strength: DF and PF dynamometer (MVT), and EMG (torque steadiness)	B (b7300)	MSk
				No change in gait pattern	3D gait kinematics and temporal–spatial parameters	B (b770, b710)	APA, IR, MSk
				No change in static balance (standing)	Stabliometry: standing COP sway	B (b755)	IR, MSk
				Improved spasticity of ankle PF in both groups ($p<0.001$)	Modified Ashworth Scale	B (7350)	MSk
				No change in gross motor performance	GMFM-66	A (d410–d429, d455)	APA, IR, MSk
Reactive balance							

Table I: Continued

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
El-Shamy et al.[50]	Group, II, Moderate	Reactive balance training with Biodex balance system	CP (spastic diplegic); GMFCS I–II; 10–12y; n=30	Improved limits of stability (p<0.001)	Biodex, DSL level 12: movement of COP with visual feedback	B (b760)	APA, IR, sensory
				Improved (reduced) falls risk (p<0.05)	Biodex: COP pathway in response to perturbation calculation of falls risk	A (d450)	RPA, NMR
				Improved functional standing balance (p<0.05)	Paediatric Balance Scale	A (d4103, d4104–d4106, d4153–d4154, d4200, d4452)	APA, IR, sensory, MSk
Shumway-Cook et al.[52]	SSRD, II, Moderate	Massed practice: reactive balance training	CP; GMFCS I–II; 7–12y; n=6	Improved reactive balance in standing (p<0.05)	Stabilometry: COP time to stabilization and area in response to perturbation	B (b755)	RPA, NMR
				No change in function in standing	GMFM: D (standing)	A (d410–d429, d455)	APA, IR, MSk
Systematic reviews							
Harris and Roxborough[30]	Systematic Review, II, 8/9	Seating, ankle foot orthotics, lycra garments, motor therapy and balance training protocols	12 studies; CP; 0–19y	Improved postural control (various) following motor therapy and balance training; conflicting results for NDT; improved reactive balance following reactive balance training, artificial hippotherapy simulators, and rocker board training	Postural control in sitting, upper extremity movement control, standing balance, knee extension, pathological movement, head control, independent sitting balance, segmental level of control, dynamic stability in gait, function, goal performance, comfort, upper limb function, posture alignment, engagement with toys, caregiving, reactive balance, and motor function	Various	Various

Table I: Continued

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
Zadnikar and Kastrin[53]	Systematic Review, II, 9/9	Hippotherapy and therapeutic horse riding and hippotherapy simultors	8 studies; CP; children or adults	Improved postural control (various) with all interventions	Video, dynamic trunk/ head stability, barrel test, functional reach test, Posture Assessment Scale, Bertoti's Postural Assessment Scale, GMFM, Peabody Developmental Motor Scales, Vineland Adaptive Behavior Scales, Self-perception profile for children, Child Behaviour Checklist, Bruininks–Oseretsky Test of Motor Proficiency, passive range of anterior–posterior pelvic tilt, photography, stabilography, muscle symmetry, and EMG	Various	Various
Tseng et al.[54]	Systematic Review, II, 8/9	Equine-assisted activities and therapies (EAAT): hippotherapy and therapeutic horse riding only	14 studies; CP; 0–18y	Improved postural control (BPAS and SAS – see outcome measure description) following hippotherapy (involving children GMFCS I–IV); no change in all other measures	Betoti's Postural Assessment Scale, Sitting Assessment Scale, surface EMG (hip adductor asymmetry), Modified Ashworth Scale, stride length, GMFM-66, and GMFM-88	Various	Various
Treadmill training							
Drużbicki et al.[55]	Group, II, Weak	Treadmill training with Lukomat	CP; GMFCS II–III; 6–14y; n=18	Improved standing balance, predominantly in eyes closed condition (p<0.05)	Stabilometry: COP deviations and pathway in standing, eyes open and closed	B (b235, b755)	APA, IR, sensory
				Improved weight symmetry in standing (p value not reported)	Underfoot pressure distribution	B (b7603)	IR, sensory, MSk
Grecco et al.[56]	Group, II, Moderate	Treadmill training, no-BWS	CP; GMFCS I–II; 3–11y; n=15	Improved standing balance in eyes open and closed conditions for AP (p=0.03), and eyes open for ML (p=0.04)	Stabilometry: COP oscillation in standing, eyes open and closed	B (b235, b755)	IR, sensory, MSk
				Improved functional balance in standing (p=0.01)	Berg Balance Scale	A (d4103, d4104–d4106, d4153–d4154, d4200, d4452)	APA, IR, sensory

Table I: Continued

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
Trunk-targeted training							
Unger et al.[57]	Group, II, Moderate	Trunk-targeted exercise with vibration	CP; GMFCS I–III; 6–13y; n=27	Improved postural alignment: AP angle sitting and standing, and shoulder-to-seat height in sitting ($p<0.05$)	2D photographic posture analysis in standing	B (b7101)	MSk
				Improved abdominal muscle thickness (RA, OE, OI, and TrA, $p<0.05$)	Ultrasound imaging: resting abdominal muscle thickness	B (d7300)	MSk
				Improved abdominal muscle strength ($p<0.001$)	Total sit-ups in one minute	B (d7300)	MSk
				Improved functional walking ability ($p<0.001$)	1min walk test	A (d4500)	APA, IR, MSk
Virtual reality							
Ramstrand and Lygnegård[58]	Group, II, Weak	Virtual reality: Nintendo Wii, Wii Fit, and Wii balance board	CP; GMFCS I–II; 8–17y; n=16	No change in standing balance	Stabilometry: mean velocity of COP during modified sensory organization test	B (b235, b755)	APA, IR, NMR, sensory
				No change in reactive balance	Response to perturbation from platform: EMG on distal leg muscles	B (b755)	RPA, NMR
				No change in directional control and synchronization of movement in standing	Rhythmic weight shift test	A (d4106)	APA, IR
Jelsma et al.[59]	SSRD, II, Strong	Virtual reality: Nintendo Wii, Wii Fit, and Wii balance board	CP; GMFCS I–II; 7–14y; n=14	No results reported	Goniometry lower limb	B (b7100)	MSk
				Improved balance in standing ($p<0.043$); no change in running	Bruininks—Oseretsky Test of Motor Proficiency: balance and running speed, and agility subsections	A (d450, d4552)	APA, IR, RPA, sensory, MSk
				Deterioration in stair function	Timed-up and down stairs test	A (d4551)	APA, IR, MSk
Brien and Sveistrup[60]	SSRD, III, Strong	Virtual reality: 2D virtual world	CP; GMFCS I; 13–18y; n=4	Improved high level functional balance and mobility in everyday function (true change from mean of the baseline significant)	Community balance and mobility scale	A (d4500, d4552, d4553, d4106, d4101)	APA, IR, sensory
				Improved functional walking capacity (MDC CI 80%, significant)	6-min walk test	A (d4501)	APA, IR, MSk
				No change in functional mobility	Timed-up and down stairs	A (d4551)	APA, IR, MSk
				No change in gross motor function	GMFM (total)	A (d410–d429, d455)	APA, IR, MSk

Table I: Continued

References	Design, evidence level, and conduct rating	Intervention	Participants	Results	Outcome measure	ICF (proposed code)	PC component measured
Visual biofeedback							
Ledebt et al.[61]	Group, II, Weak	Visual biofeedback	CP; GMFCS I; 5–11y; n=10	Improved static and dynamic standing balance: maintaining COP on target (p=0.023), and voluntary displacement AP (p<0.05)	Stabilometry: (1) time of COP on target and max displacement; (2) maximum *voluntary* COP displace	B (b760)	APA, IR, SS
				Improved gait (increased step length [p=0.015] and decreased asymmetry [p=0.021])	4m walkway with two force plates	B (b770)	APA, IR, MSk

Group, group research design; CP, cerebral palsy; B, 'body functions and structures'; MSk, musculoskeletal; GMFM, Gross Motor Function Measure; A, 'activity'; APA, anticipatory postural adjustments; IR, internal representations; TBI, traumatic brain injury; GMFCS, gross motor functional classification system; SSRD, single-subject research design; COP, centre of pressure; AP, anteroposterior; ML, mediolateral; CI, confidence interval; DSL, dynamic stability limits; RPA, reactive postural adjustments; NMR, neuromuscular response synergies; MVT, maximal voluntary torque; DF, dorsiflexion; PF, plantarflexion; EMG, electromyography; RA, rectus abdominis; OE, obliquus externus; OI, obliquus internus; TrA, transversus abdominis; MDC, minimal detectable change; SS, sensory strategies.

reviews, were identified (Table I). Sixteen hours of therapy (two 1h sessions/wk for 8wks) improved sitting balance (BF&S; evidence level II, conduct weak; see Table SIIIa)[45] and standing balance ('activity'; evidence level III, conduct moderate; see Table SIIIa)[47] for ambulant, school-aged children (GMFCS I–II). In contrast, no improvement was seen for younger (2–5y), non-ambulant (GMFCS V) children receiving lower-dose (8h) hippotherapy (one 1h session/wk for 8wks) in sitting balance (BF&S and 'activity'; evidence level III, conduct moderate; see Table IIIb).[46] Two systematic reviews, published in 2011 and 2013, concluded that children with less severe spastic CP were more likely to show improvements in postural control following hippotherapy compared with more severely affected children.[53,54]

Hippotherapy simulators

Hippotherapy simulators were developed to imitate the movement of a horse in an attempt to make hippotherapy accessible in a clinical setting.[49] Four studies were identified, which included two level II studies and one systematic review (Table I). These showed that simulator training has a mixed ability to improve postural control at BF&S and 'activity' components. Simulator training for 2.5 hours (one 15min session/wk for 10wks) did not improve sitting balance (BF&S and 'activity') in a heterogeneous group of children with CP (GMFCS I–IV, predominantly non-ambulant GMFCS IV) (evidence level II, conduct strong; see Table SIIIa).[49] A higher dose of 8 hours (two 40min sessions/wk for 6wks) improved sitting balance (BF&S) in another heterogeneous group of children with CP (GMFCS II–IV) (evidence level II, conduct weak; see Table SIIIa).[48] A systematic review,[53] which preceded these two studies, included predominantly sources of low-level evidence; although it included a meta-analysis of seven studies, which demonstrated statistically significant improvement in postural control, this result was confounded by the inclusion of simulator studies along side other studies of equine-assisted activities and therapies (hippotherapy [n=3] and therapeutic horse riding [n=3]).[53]

Neurodevelopmental therapy

Because NDT has been an evolving concept since the 1940s, studies were included if they met any of the criteria reported in a previous AACPDM review of NDT.[62] As a result, NDT was identified as a comparison treatment in seven studies, of which six were level II or III (Table I). An unspecified dose of NDT alone,[41] or NDT ('based on the Bobath technique') combined with 'conventional rehabilitation' treatments (i.e. joint mobility, muscle strengthening, and mobility activities),[42] improved postural alignment (BF&S, two of level II, conduct weak; see Table SIIIa) over 6 weeks in children with spastic diplegia, aged between 8 months and 10 years.[41,42] An unknown dose of therapy 'focused on improving walking and balance through facilitation and normalization of movement patterns', delivered over 5 weeks, led to an average 1.80 second decrease in 'timed-up and go' test scores in children with quadriplegia and diplegia (GMFCS I–III), aged between 4 years and 11 years ('activity'; level II, conduct moderate; see Table SIIIa). However, the statistical significance of this decrease was not reported.[44] Eight hours (two 40min sessions/wk for 6wks) of NDT focusing on trunk control improved postural control in sitting (BF&S) in children with spastic diplegia (GMFCS II–V), aged 3 to 10 years (level II, conduct weak, see Table SIIIa).[48] The statistical significance of this change was not reported. NDT (composed of stretching, strengthening exercises, standing exercises, postural reactions exercises, reflex-inhibiting patterns, and gait training exercises) for 72 hours (three 120min sessions/wk for 12wks) improved limits of stability (BF&S) and standing balance ('activity'), and reduced fall risk ('activity'), in children with spastic diplegic CP, GMFCS I–II (evidence level II, conduct moderate; see online Table SIIIa).[50] In contrast, 8 hours (two 30min sessions/wk for 8wks) of NDT did not improve standing balance ('activity') in children with bilateral spastic CP (GMFCS I–II), aged 4 to 10 years (level III, conduct moderate; see Table SIIIa).[47]

Progressive resistance exercise

Progressive resistance exercise involves resisted motion or lifting tasks, with structured increases in training loads, to improve muscle strength. One study (evidence level II) was identified (Table I). Performing resisted ankle and knee exercises for a total of 6 hours (two 15 min sessions/wk for 12wks), combined with rehabilitation (12h), did not improve standing balance (BF&S; as measured by stabilometry [sway path length], $p>0.05$) or gait kinematics (BF&S) in ambulant children with CP (GMFCS I), aged 5 to 14 years (level II, conduct strong; see online Table SIIIa).[51]

Reactive balance training

Reactive balance training involves repeated practice of balance recovery, when standing on a support surface that is perturbed without warning in a forward, backward, or lateral direction. Three studies were identified, of which two were level II (Table I).[50,52] Training using a laboratory-based force platform for approximately 2 hours (one 20–25min session/d for 5d [100 perturbations/session]) improved standing balance (BF&S) in ambulant children with CP (GMFCS I–II) (level II, conduct moderate; see Table SIIIa). Training using the Biodex balance system, for a higher dose of 18 hours (three 30min sessions/wk for 12wks), improved limits of stability (BF&S) and standing balance ('activity'), and reduced fall risk ('activity'), in children with spastic diplegic CP (GMFCS I–II) (evidence level II, conduct moderate; see Table SIIIa].[50] This protocol also included an unspecified duration of anticipatory balance training (voluntary movements of the center of mass to the limits of stability with visual feedback).

Treadmill training with no body weight support and treadmill training with partial or full body weight support

Treadmill training includes walking or running on a treadmill with F-BWS, P-BWS or no-BWS. Of six studies, two were level II (Table I). The first included training with no-BWS, and the second involved P-BWS or F-BWS with robotic assistance using the Lokomat.[55,56] Treadmill training with no-BWS, for children with CP GMFCS I–II, improved BF&S and 'activity' components:[56] training for 7 hours (two 30min sessions/wk for 7wks) improved standing balance (BF&S), which demonstrated improved overall balance ('activity') (level II, conduct moderate; see Table SIIIa).[56] Training with P-BWS or F-BWS and robotic assistance (Lokomat) for 15 hours (five 45min sessions/wk for 4wks), by ambulant and semi-ambulant children with spastic diplegia (GMFCS II–III), improved standing balance (BF&S), and foot loading symmetry with eyes open (BF&S; level II, conduct weak; see Table SIIIa);[55] no 'activity'-level measures were evaluated. One study reported intermittent discomfort and 'a few' skin abrasions from robotic orthosis use; these issues were resolved by adjustment of the supports (see Table SIV).[63]

Trunk-targeted training

Trunk-targeted training involves exercises aimed at improving trunk muscle strength and control. Two studies were identified, of which one was level II (Table I).[57] In this study, trunk-strengthening exercises were performed whilst participants were positioned on a vibrating platform for between 1.5 and 2.5 hours over 4 weeks (two 5–10min sessions/wk for 2wks, followed by four or five 5–10min sessions/wk for a further 2wks). This protocol improved postural alignment (BF&S), increased resting abdominal muscle thickness (BF&S), and increased functional muscle strength (BF&S). All improvements were maintained after 4 weeks, except resting muscle thickness of the transversus abdominis and internal oblique, and performance on the 1-minute walk test (evidence level II, conduct moderate; see Table SIIIa). The link between BF&S (transversus abdominis and internal oblique thickness) and 'activity' (1min walk test) was not evaluated.

Upper limb interventions

Two upper limb intervention studies were identified, each using a different approach: constraint-induced movement therapy[64] or force use therapy[65] (see Table SIIa). Both studies were classified as level IV (demonstrating low levels of evidence), and, therefore, did not meet criteria for further evaluation.

Virtual reality

Virtual reality involves balance training whilst playing computer games that create a virtual environment using artificial sensory information to simulate real-life experiences or activities.[66] Virtual reality is used in rehabilitation to achieve therapy goals within a play environment.[66] Out of eight studies, three were level II or III (Table I).

Conflicting results were obtained on the impact of virtual reality on the ICF BF&S and 'activity' components. Two studies involved the Nintendo Wii Fit. Five hours (four 25min sessions/wk for 3wks) of supervised Wii Fit training, in a physiotherapy clinic, playing games aimed at improving standing balance and weight shift, resulted in improved standing balance ('activity') for children with spastic hemiplegia, GMFCS I–II (level I, conduct strong; see Table SIIIb).[59] However, stair climbing was unchanged or, in some cases, deteriorated. A higher dose of 12.5 hours (five 30min sessions/wk for 5wks) of unsupervised Wii Fit balance games at home did not improve standing balance (BF&S and 'activity') for ambulant children with hemiplegia or diplegia, GMFCS I–II (level II, conduct weak; see Table SIIIa).[58] The third study involved a 2D virtual world game. Intensive training for 7.5 hours (ten 45min sessions over 1wk) improved functional balance ('activity') for adolescents with CP GMFCS I (level III, conduct strong; see Table SIIIb).[60]

Visual biofeedback

One study of visual biofeedback was identified, which had a level II evidence rating (Table I). It involved standing on a balance platform in a laboratory (no specifications provided) and keeping the centre of pressure, represented as a red dot on a computer screen, static, or shifting it to a target. Anticipatory training for 9 hours (three 30min sessions/wk for 6wks) improved static standing balance (BF&S) and dynamic standing balance (BF&S) in ambulant children with CP, GMFCS I (level II, conduct weak; see Table SIIIa).[61] No 'activity'-level measures were included.

DISCUSSION

This systematic review analysed 45 studies of children with CP, and presented information on the use of 13 different postural control interventions; 40 of these studies, and nine of these interventions, had not been included in a previous systematic review on postural control interventions, published in 2005. There is moderate evidence to support the use of five of these interventions: hippotherapy, treadmill training with no-BWS, trunk-targeted training, reactive balance training, and gross motor task training. There is only weak or conflicting evidence to support the use of six of these as effective postural control interventions: hippotherapy simulators, treadmill training with P-BWS or F-BWS (including robotic assistance), NDT, virtual reality, visual biofeedback, and FES. For the remaining two interventions, either there were no high-level protocols (level I–III) evaluating efficacy (upper limb interventions) or the evidence suggests that there is no improvement in postural control (progressive resistance exercise). With the possible exception of NDT, it was noted that all of the effective interventions were reported by studies involving ambulant children with CP (GMFCS I–III).

Of the five intervention types that gained moderate support, hippotherapy was the most commonly reported (five level I–III studies). Hippotherapy improved postural control in ambulant children with CP when provided for at least 16 hours. It appears to impact multiple postural control components, including anticipatory and reactive postural adjustments, and sensory and musculoskeletal systems. Effective elements of hippotherapy are proposed to include the horse's movement, which has been suggested to challenge balance, improve posture and strength while incorporating sensory input,[67] and simulate human gait and the vertical change in the centre of pressure;[68] and the warmth and rhythm of the horse, which may promote relaxation, thereby reducing spasticity and increasing muscle length.[53] Hippotherapy may also provide the opportunity for trunk muscle motor control training, similar to that achieved with therapy ball activities. The novelty of hippotherapy promotes extended engagement, and the opportunity for massed practice of reactive postural adjustments.[30] Two previous systematic reviews support the current findings, including the conclusion that hippotherapy is more effective for ambulant children with CP (GMFCS I–II) than for children with more severe CP.[53,54]

Although moderate evidence supports the use of hippotherapy, the use of hippotherapy simulators cannot be supported by this systematic review because of conflicting outcomes between studies and the levels of the ICF components considered. The limitations of the two level II studies[48,49] which explored the use of hippotherapy simulators, when compared with the studies of hippotherapy, included heterogeneity of participants (GMFCS I–IV); varied intervention dose (2.5–8h); and a lack of individualization in training protocols. Future research could address these limitations. The systematic review[53] of hippotherapy simulator use provided little additional information because outcomes were pooled with both hippotherapy and therapeutic horse riding.

Treadmill training with no-BWS was the second most common approach, gaining moderate support, with one level II study.[56] For ambulant children with CP, training for at least 7 hours improved musculoskeletal and sensory components, and anticipatory postural adjustments. The use of a specific protocol, guiding the gradual increase in treadmill speed for children who are walking independently (GMFCS I–II), appears to be critical to the success of this approach. In contrast, there was only weak evidence supporting the use of treadmill training with F-BWS or P-BWS for semi-ambulant children (GMFCS II–III), despite a higher dose of 15 hours (5wks×4 sessions×45min).[55] This is not surprising given that the goal of treadmill training is to improve anticipatory and reactive postural adjustments, which are reduced when robotic support is present.[69] A systematic review of P-BWS treadmill training, including robotic assistance, for children with CP, supports these findings, concluding that while treadmill training with P-BWS is effective for improving important gait elements, such as endurance, speed, and gait patterns,[70] there is a need for further research, with standardized protocols, to determine if it is effective in improving postural control for children with lower-level mobility.

Trunk-targeted training (one level II study) was a novel combination of interventions (strengthening exercises on a vibrating platform) that was shown, by moderate-level evidence, to improve anticipatory, sensory, and musculoskeletal components of postural control in ambulatory children with CP, when provided in short bursts totalling only 1.5 to 2.5 hours.[57] The authors were unable to determine the relative effectiveness of the 'strength' and 'vibration' components of this protocol. They proposed that vibration 'activated weak and dormant muscles', and reduced the need to use weights or high repetitions to strengthen abdominal muscles for postural control.[57] A separate review of vibration therapy supports this concept, proposing that it perturbs the gravitational field to activate and strengthen muscles, stimulate peripheral sensory receptors, and evoke postural responses.[71] In children with CP, vibration alone can improve gross motor function and bone density;[72] further research is needed to establish the effects of vibration on postural control. Trunk muscle motor control training has been shown to improve anticipatory postural adjustments[73,74] and gait[57] in adult populations, and so appears to be a contender for further treatment development. A mechanism for achieving efficient trunk muscle activation and strengthening in children with atypical muscle tone, spasticity, and motor control issues remains a challenge.

There was moderate evidence to support the use of reactive balance training alone as an intervention to improve reactive postural adjustments in ambulant children with CP, with at least 2 hours of training, but it did not improve self-initiated movement control (Gross Motor Function Measure [GMFM]).[52] However, when reactive balance training (Biodex system) was combined with anticipatory training (voluntary leaning towards the limits of stability), both reactive postural adjustments and self-initiated movement control did improve.[50] A comparison of these two studies confirms the impact of specificity of training on postural control. Reactive balance training may improve recovery from external perturbations, such as a trip or movements when standing on a bus; if the goal of therapy is to improve control of self-initiated motor function, then anticipatory training may be more appropriate. More research is warranted to determine the extent to which reactive balance training alone influences other postural control elements, ICF components, and postural orientation, and not just stability.

The use of gross motor task training (two level II studies) was supported by moderate-level evidence to improve postural control in ambulant children with CP when provided for at least 10 hours.[43,44] Gross motor task training affects most postural control elements because the development of efficient anticipatory and reactive postural adjustments occurs in parallel with the attainment of a gross motor skill, and variability in practice can then fine-tune control of that task.[3,75] Both papers also highlight the concept of specificity of practice,[43] which is important when designing programmes to address functional goals. This approach has high clinical utility because it requires no technical equipment, and can be delivered in most settings. Further research is required to determine the minimum required dose, as total training times ranged from 10 to 30 hours in the studies considered by this review.

Six intervention approaches showed weak or conflicting evidence. Hippotherapy simulators and treadmill training with P-BWS or F-BWS have been addressed in previous paragraphs. Overall, NDT was the most commonly evaluated intervention in this category (six level II–III studies), as it was frequently included as a comparison when testing potential new interventions. Unfortunately, although it appeared in six high-level studies, it is difficult to assign more than a weak evidence level to this intervention for several reasons. Primarily, studies often lacked a clear description of the specific framework or intervention content of the NDT component provided, or how fidelity was maintained across participants or therapists. Furthermore, it was combined with other therapies and so the effective postural control element was not possible to determine. At times, dose was delivered in unspecified or variable formats. In other cases, participants were heterogeneous in GMFCS or age. It would be useful to address these methodological limitations in future research so that the relative benefit of NDT for postural control in children with CP can be more clearly understood, particularly for children with more severe motor impairment, where it may be of particular benefit.

Virtual reality (three level I–III studies)[58–60] is gaining popularity as a result of the increasing availability of relevant home- and laboratory-based technologies. Although it received weak support as a postural control intervention, it is proposed to influence anticipatory and sensory components through practice of voluntary movement, in conjunction with feedback through visual (screen) and/or tactile (hand control) modalities. It is suggested to fulfil three important requisites for motor learning: (1) movement repetition; (2) active participation; and (3) performance feedback.[76] Lack of rigorous research conduct makes it difficult to draw conclusions about the effects of virtual reality on postural control. One author recommends that virtual reality be used only as an adjunct to other therapies, and not as a replacement.[59] A review of virtual reality use by children with CP, which included motor but not postural control outcomes, agrees that substantial benefits could be gained from using virtual reality; however, the current evidence is weak.[66]

Visual biofeedback (one level I–III study)[61] and FES (two level I–III studies)[41,42] are the remaining two intervention types to show weak evidence. Both demonstrated broad efficacy in improving postural stability and orientation. Both approaches require more detailed reporting of participant groups and/or evaluation of higher participant numbers, as well as more detailed treatment protocols, to establish a sufficient level of guidance for evidence-based practice.

Two interventions showed no impact on postural control. Progressive resistance exercise (one level II study)[51] showed no effect on children with CP. This finding is supported by studies with adult populations, which have suggested that, rather than strengthening, neuromuscular control training is required to improve postural control.[77] This recommendation is consistent with the moderate support found for functional strength training during gross motor tasks, as discussed earlier. Finally, there were no high-level upper limb interventions suitable for reporting at this stage. Ballaz et al.[65] contend that investigating postural control outcomes following constraint-induced movement therapy and force use therapy is important to assess the effect of reducing asymmetric upper limb function on balance (postural stability) and postural symmetry (orientation). More rigorous research is required before it is possible to recommend these approaches specifically as effective postural control interventions.

Outcome measures

This review highlights the importance of selecting appropriate outcome measures when assessing the potential impact of each intervention. Progress has been made, but broader evaluation is required to establish a thorough understanding of the effects of each intervention on (1) overall postural stability and orientation functions; (2) postural control elements according to the systems theory approach; and (3) 'function' (BF&S), 'activity', and 'participation' according to the ICF. The majority of studies reported in this review measured postural stability outcomes, especially the ability to 'maintain' or 'restore' balance; however, fewer studies have measured the ability to 'achieve' balance, or improve orientation of body segments relative to the task and environment. Furthermore, new measures may better quantify the impact on postural control elements; for example, the recently described Balance Evaluation Systems Test (BESTest)[27] or the miniBESTest,[78] which were developed to differentiate the six postural control elements of the systems control approach. Neither of these tests has been validated for use with children. Finally, our review shows that outcomes were generally measured at the ICF BF&S (impairment) or 'activity' (basic motor skill) levels, with no exploration of the impact on 'participation'. There is great scope for future research to explore the potential carry-over from postural control interventions to 'activity' and 'participation' functions, which may be assessed by using, for example, the Canadian Occupational Performance Measure, Goal Attainment Scale, or the The Children's Assessment of Participation and Enjoyment.

Limitations and future direction for research

It is possible that other exercise interventions may affect postural control to some degree. If an intervention study did not include a postural control outcome measure, it was excluded from this review and, therefore, some effective exercise interventions may not be represented here. This highlights the importance of including postural control measures in future studies of exercise interventions. This review also reports on many positive gains made in postural control intervention design and evaluation in the last decade. It highlights where further research is needed if intervention types are to achieve higher levels of evidence. In particular, a focus on improving treatment description and fidelity, establishing dosage and measuring both short- and long-term effects for subgroups in the CP population, is required. Finally, there is a need for further research into programmes that are innovative, provide multidimensional impact on components of postural control, and include functional exercise. Mainstream programmes, such as yoga, Pilates, and tai chi, which are popular with adults, are now being offered to children. The intent of these programmes is to improve posture and motor control; however, their efficacy for children with CP has yet to be investigated.

CONCLUSION

Exercise interventions documented to improve postural control for children with CP are increasing. This review has identified five potentially effective interventions, six that require more investigation, and two that are probably ineffective. Further research is required for children with different types and severities of CP to establish (1) responsive and reliable postural control outcome measures; (2) effective treatment selection and dose guidelines; and (3) possible efficacy of mainstream exercise interventions that have demonstrated effectiveness for improving postural control in adults with brain injury, such as Pilates, yoga, and tai chi.

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SUPPORTING INFORMATION

The following additional material may be found online:

Table SI: Levels of evidence for group and single-subject design studies.

Table SII: (a) Summary of group studies – interventions and participants. (b) Summary of single-subject studies – interventions and participants.

Table SIII: (a) Conduct of group design studies. (b) Conduct of single-subject design studies. (c) Conduct of systematic review.

Table SIV: Reported adverse events.

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