Systematic Review of Progressive Strength Training in Children and Adolescents with Cerebral Palsy Who Are Ambulatory

Margaret Mockford, MSc, MCSP, and Janette M. Caulton, MSc, MCSP

Physiotherapy Department (M.M.), Blackfriars School, North Staffordshire NHS Primary Care Trust, Newcastle-under-Lyme, Staffordshire, United Kingdom; and School of Health and Rehabilitation (J.M.C.), Faculty of Health, Keele University, Keele, Staffordshire, United Kingdom

Purpose: To capture and analyze the evidence concerning the effects of progressive strength training on function and gait in children and adolescents with cerebral palsy (CP) who are ambulatory. Method: A language-inclusive search was conducted for controlled or noncontrolled studies of strength training for subjects with CP who were ambulatory and aged 4 to 20 years, using objective outcome measures. Quality was assessed with the Maastricht-Amsterdam List. Data were extracted and analyzed. Results: The 13 included articles favored treatment without significant adverse effects. Function and gait improved more following isotonic rather than isokinetic training, and in younger rather than older subjects. Conclusions: Function and gait improvements were greater in preadolescents. (Pediatr Phys Ther 2008;20:318–333) Key words: adolescent, cerebral palsy, child, exercise therapy, human movement system, muscle strength, physical therapy, state of the art review, treatment outcomes

INTRODUCTION

Cerebral palsy (CP) is defined as “...non-progressive, but often changing, motor impairment syndromes secondary to lesions or anomalies of the brain arising in the early stages of its development.” CP occurs in approximately 2 of every 1000 live births in Europe and 2.4 of every 1000 live births in the United States. Motor abilities develop during childhood but eventually a plateau is reached. Children risk losing some functional abilities during adolescence because of ongoing secondary impairments such as soft tissue shortening, weakness, and bony deformity. In particular, teenagers who are ambulatory may lose distance, speed, or quality of walking. Recent government legislation in the United Kingdom focuses attention on preparing children for adult life; as participation in society is correlated with independent mobility, it is important to examine gait deterioration.

Strength-training interventions involve effort against progressive resistance. Historically, clinicians attempted to address weakness in subjects with CP by applying the principles of DeLorme in strength-training programs. With the advent of neurodevelopmental therapy, however, clinical practice largely followed the teaching that weakness is not a major problem in CP. Treatment was focused on inhibiting spasticity, and excessive effort was avoided as it was believed to increase spasticity and impair motor control. More recently, experts have questioned these premises, in identifying that both spasticity and weakness are part of the upper motor neurone syndrome and may co-exist in the same muscle. There is some evidence that function is related to both strength and spasticity. Children with CP are significantly weaker than their peers and weakness may be evident in all muscles around a joint.
Two previous reviews of strength training in CP found all included studies indicated the intervention increased muscle strength. A systematic review of literature published up to March 2000 used a thorough search strategy, but was limited to English language papers. The review included upper and lower limb studies of subjects with CP both ambulatory and nonambulatory; most were children and teenagers, but 1 study included adults up to 47 years. The broad inclusion criteria increased clinical heterogeneity and generalizability but limited internal validity. All 23 included studies favored strength training but negative studies may have been missed by exclusion of non-English papers. The authors concluded strength training improves strength but further research is needed to ascertain activity and participation outcomes, to establish optimum dosages, and to investigate longer-term effects.

The current review included non-English papers, and limited the clinical heterogeneity through a more focused research question. This review aimed to ascertain the current worldwide evidence about progressive strength training for children and adolescents with cerebral palsy who are ambulatory, with particular regard to function and gait outcomes.

**METHOD**

**Search Strategy**

A comprehensive language-inclusive search strategy was devised. This was validated by an experienced medical librarian. The search strategy was applied to 8 databases (MEDLINE, AMED, CINAHL, Cochrane Library, EMBASE, PEDro, PsychInfo, and SPORTDiscus) without limitations on publication dates up to March 2007. The keywords were as follows: population cerebral palsy; intervention strength training, strengthening, strength exercise, weight training, weight lifting, resisted exercise, resistance exercise, resisted training, resistance training. A supplementary search attempted to find literature missed by electronic searching. Expert researchers in the field were contacted, in an effort to locate any unpublished studies. Details of the search strategy are available from the authors.

**Inclusion/Exclusion Criteria**

The inclusion criteria for this review were (1) any experimental or quasi-experimental study, or single-group preexperimental studies; involving (2) subjects aged 4 to 20 years with cerebral palsy, ambulatory with/without aids and able to follow simple instructions; (3) any intervention aimed at strengthening one or more lower limb muscles and with some means of exercise progression; (4) any objective measure of walking ability, function, and/or strength. These criteria were narrower than those of the previous review as upper limb studies, adults, and subjects who were nonambulatory were excluded.

**Study Selection**

Initially, the inclusion criteria were applied liberally to the citations, the abstract of each likely citation was read and the full manuscript obtained of each of those possibly meeting the inclusion criteria. If the abstract was unavailable, the full manuscript was obtained. Foreign language papers were translated. The inclusion criteria were stringently applied to each full manuscript by 2 independent reviewers to yield a final set of papers. If a full manuscript or translation was unobtainable, that paper had to be excluded.

**Quality Assessment and Levels of Evidence**

The Maastricht-Amsterdam List (MAL) quality assessment tool was chosen for this review as it scores both controlled and noncontrolled studies. Two independent reviewers applied the full 19-item MAL to controlled studies and the modified 14-item MAL to noncontrolled studies. Assessment reliability was increased by use of Operationalisation Guidelines (Appendix A) devised from the guidelines for the tools from which the MAL had been derived. These Guidelines were refined through a 3-stage pilot study by the 2 reviewers. This resulted in the level of agreement, as measured by the unweighted kappa statistic, between the 2 reviewers rising from 0.6162 (standard error 0.0742; 95% confidence interval 0.4708–0.7616) to 0.7194 (standard error 0.1095; 95% confidence interval 0.5047–0.9341). This indicates the strength of agreement increased from “moderate/substantial” to well within the “substantial” range. The frequent disagreements over items k and n were eradicated and the items on which they disagreed became more random.

The total score and the subscores for descriptive, internal validity, and statistical criteria were tabulated and compared with the MAL bench-mark scores (Table 1). Sackett’s Levels of Evidence and Grades of Recommendation guidelines were also applied to the included studies (Appendix B).

**Data Extraction and Analysis**

The MAL quality scores were converted to percentages to enable comparisons. Data were extracted from each included study. Meta-analysis was beyond the scope of this review and was likely to be inappropriate because of heterogeneity of studies; descriptive statistics, however, were used to summarize findings. Within-group effect size statistics were calculated where possible and then averaged.

---

**TABLE 1**

Maastricht-Amsterdam List Quality Bench-Mark Scores

<table>
<thead>
<tr>
<th></th>
<th>Controlled Studies</th>
<th>Noncontrolled Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Subscore</td>
<td>Score for “High” Quality</td>
</tr>
<tr>
<td>Internal validity criteria</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Descriptive criteria</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Statistics criteria</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
The intervention was carried out for a period of 2 to 6 months, with a follow-up period of 1 to 3 months. The results were analyzed using the Maastricht-Amsterdam List quality scores for the randomized clinical trials, which ranged from 7 to 11, and for the noncontrolled studies, which ranged from 5 to 14.

**TABLE 2**

Maastricht-Amsterdam List Sectional Scores and Levels of Evidence

<table>
<thead>
<tr>
<th>Study (Author and Year)</th>
<th>Randomized clinical trials</th>
<th>Subtotal Internal Validity Criteria</th>
<th>Subtotal Descriptive Criteria</th>
<th>Subtotal Statistical Criteria</th>
<th>Maastricht-Amsterdam List Total Score</th>
<th>Level of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dodd et al, 2003⁵³</td>
<td>b l f g i j l n = 7</td>
<td>d a k m l m₂ = 5</td>
<td>o q = 2</td>
<td>14 = 74%</td>
<td>1b</td>
<td></td>
</tr>
<tr>
<td>Engsberg et al, 2006³⁵</td>
<td>j l n = 3</td>
<td>a c d k m l = 5</td>
<td>o q = 2</td>
<td>10 = 53%</td>
<td>2b</td>
<td></td>
</tr>
<tr>
<td>Jiang et al, 2006⁶⁶</td>
<td>j = 1</td>
<td>a c m l = 3</td>
<td>o q = 2</td>
<td>6 = 32%</td>
<td>2b</td>
<td></td>
</tr>
<tr>
<td>Liao et al, 2007³⁷</td>
<td>f g i j l n = 6</td>
<td>a c d k m l = 5</td>
<td>o q = 2</td>
<td>13 = 68%</td>
<td>1b</td>
<td></td>
</tr>
<tr>
<td>Unger et al, 2006⁴¹</td>
<td>b i j l n = 5</td>
<td>a m l = 2</td>
<td>o q = 2</td>
<td>9 = 47%</td>
<td>2b</td>
<td></td>
</tr>
<tr>
<td>Noncontrolled studies</td>
<td></td>
<td>Max Score, 7</td>
<td>Max Score, 5</td>
<td>Max Score, 2</td>
<td>Max Score, 14</td>
<td></td>
</tr>
<tr>
<td>Blundell et al, 2003⁵⁹</td>
<td>f g i j l n = 5</td>
<td>a d m l m₂ = 4</td>
<td>q = 1</td>
<td>10 = 71%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Damiano et al, 1995a³⁰</td>
<td>f g j l n p = 7</td>
<td>a d m l = 3</td>
<td>o q = 2</td>
<td>12 = 86%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Damiano et al, 1995b³¹</td>
<td>f g j l n p = 6</td>
<td>a d k m l = 4</td>
<td>o q = 2</td>
<td>12 = 86%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Damiano and Abel, 1998¹²</td>
<td>j l n p = 5</td>
<td>a k m l = 3</td>
<td>o q = 2</td>
<td>10 = 71%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Eagleton et al, 2004⁴¹</td>
<td>j n = 2</td>
<td>a m l = 2</td>
<td>0</td>
<td>4 = 29%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>MacPhail and Kramer, 1995³⁸</td>
<td>g l j n p = 5</td>
<td>a d k m l m₂ = 5</td>
<td>o q = 2</td>
<td>12 = 86%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Morton et al, 2005³⁹</td>
<td>g i j l n p = 6</td>
<td>a d k m l m₂ = 5</td>
<td>o q = 2</td>
<td>13 = 93%</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Tweedy, 1997³⁶</td>
<td>j l n = 3</td>
<td>d k m l = 3</td>
<td>o = 1</td>
<td>7 = 50%</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

Eighty-seven studies were identified by abstracts. Thirty-four full articles were reviewed, including 4 non-English studies. Finally, 13 studies were included in this review, including 1 non-English study. No study was excluded because of translation difficulties, but 3 of the 4 unobtainable studies were non-English.

The Maastricht-Amsterdam List quality scores for the included studies are shown in Table 2. Two high-quality RCTs gave level 1b evidence and 3 low-quality RCTs gave level 2b evidence. The 8 noncontrolled studies gave level 4 evidence of which 6 met the criteria for “sufficient quality” and 2 were of lower quality. The 5 RCTs yield a grade B recommendation for treatment (Appendix B).

Internal validity was compromised by lack of blinding. Subjects and therapists cannot be blinded to strength training but only 6 of 13 studies blinded the assessors (Table 2). Avoidance of cointerventions was inadequate in 8 of 13 studies and adequate compliance was described in only 7 of 13 studies.

The method of randomization was not clear in 3 of 5 RCTs. However, most studies either had no drop-outs or described these subjects adequately. The descriptive and statistical criteria of the MAL tool were mostly fulfilled with the exception of a long-term outcome which was carried out in only 4 studies.

A total of 138 subjects participated in strength training, most were described as having spastic-type CP, mainly of hemiplegic or diplegic distribution. Most studies provided the intervention 3 times per week (range 1–5) over 6 weeks (range 4–12). Ten studies involved open and/or closed chain isotonic exercises and 25,38 gave isokinetic exercises. Resistance was applied using free weights, body weight, weighted backpacks, elastic bands, weight machines, or an isokinetic machine. Most studies included warm-up and cool-down activities, some included stretches or balance exercises, but all described strength training as the major intervention. The setting varied but all except one had adult supervision.

Study data are shown in Tables 3 and 4. Data for function and gait outcomes were incomplete as some studies did not provide sufficient information for effect sizes to be calculated. Data could not be pooled due to heterogeneity between studies and missing data. The 2 reports of the study by Damiano et al were considered 1 study to avoid double-counting.

**Strength**

Seven studies measured isometric strength and overall this was increased following isotonic exercising. The 2 studies using isokinetic exercises measured results isokinetically and found a significant improvement. One study providing isotonic exercises found both isokinetic and isometric strength was improved. Measures of effect all favored treatment, with 7 of these regarded as large effects (Table 5).

Two studies found strengthening the quadriceps moved the quadriceps-hamstrings ratio further from the normal, but 1 study strengthened quadriceps and hamstrings and found the ratio moved nearer to normal. One study found that isometric quadriceps strength showed greatest improvements at longer muscle lengths but another found greatest gains at shorter lengths.

**Function**

To measure functional changes, 7 studies used the Gross Motor Function Measure. Six of these...
<table>
<thead>
<tr>
<th>Study (Author and Year)</th>
<th>Design and Length</th>
<th>Subjects</th>
<th>Intervention: Frequency, Type, Resistance, Progression, Additional Activities</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blundell et al, 2003&lt;sup&gt;29&lt;/sup&gt;</td>
<td>ABA group, noncontrolled. 2 wks baseline, 4 wks intervention, 8 wks follow-up</td>
<td>n = 8. Age 4–8 yrs, mean 6.3 yrs, 7 = spastic diplegia, 1 = spastic/ataxic quadriplegia. Convenience sample.</td>
<td>1 hour sessions, 2× per wk. Isotonic closed-chain exs, as circuit. Resistance by body weight. Progressed by increasing reps/speed/difficulty. Also stretches, crouch exs for balance, treadmill for endurance—but ST major part of intervention.</td>
<td>After-school exercise group, in school, supervised by PT and parents. “Team” atmosphere.</td>
</tr>
<tr>
<td>Damiano et al, 1995a&lt;sup&gt;30&lt;/sup&gt;</td>
<td>Pre-test/post-test design. 6 wk intervention. Comparison with TD controls at baseline only.</td>
<td>n = 14. Age 6–14 yrs, mean 9.1 yrs. 11 ambulatory without aids, 3 ambulatory with aids. Self-selected volunteers. Controls: n = 25 TD, aged 3–13 yrs, mean 8.2 yrs.</td>
<td>3× per wk. Isotonic open-chain concentric/eccentric knee extension in secure sitting. 4 × 5 reps per leg. Free ankle weights at 65% 1RM, calculated as double 65% of isometric 1RM at 90° knee flexion. Weights reassessed and load progressed. Also 5 min warm-up by lower limb stretches, walking.</td>
<td>Home. Weekly review by PT. Exercise diary.</td>
</tr>
<tr>
<td>Damiano et al, 1995b&lt;sup&gt;31&lt;/sup&gt;</td>
<td>As above. No comparison with controls for 3DGA.</td>
<td>As above.</td>
<td>As above.</td>
<td>As above.</td>
</tr>
<tr>
<td>Damiano and Abel, 1998&lt;sup&gt;32&lt;/sup&gt;</td>
<td>Pretest/posttest design. 6 wks intervention.</td>
<td>n = 11. Age 6–12 yrs, mean 8.8 yrs. 6 spastic diplegia, 5 spastic hemiplegia. Convenience sample. Historical control data: 16 preadolescent TD age 5–12 yrs, mean 8.2 yrs.</td>
<td>3× per wk. Normalized strength data by body weight, then compared to control data. Diplegias: chose 2 weakest muscles as average across legs. Hemiplegias: chose 2–3 muscles showing ≥20% asymmetry. Isotonic open-chain exs. 4 × 5 reps for each muscle. Free weights: 65% isometric 1RM. Progressed load every 2 wks by reassessing 1RM.</td>
<td>Home. PT supervision every 2 wks. Exercise diary.</td>
</tr>
<tr>
<td>Dodd et al, 2003&lt;sup&gt;33&lt;/sup&gt;</td>
<td>RCT-ST versus control of normal PT and daily/physical activities. 6 wks intervention, 12 wks follow-up.</td>
<td>n = 21, randomized to ST n = 11, control n = 10. Age 8–18 yrs, mean 13 yrs. Strength-training group more severe CP, but not statistically significant (p = 0.07). 18 of 21 had prior surgery, 3 had prior BTX.</td>
<td>3× per wk. Isotonic, closed-chain. Bilat heel raise, bilat half-squats, step-ups. 3 × 8–10 reps. Weights in backpack. Progressed by additional weights every 2 wks, by PT.</td>
<td>Home. PT visited every 2 wks to supervise and increase load. Exercise diary.</td>
</tr>
<tr>
<td>Eagleton et al, 2004&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Single group AB pretest/posttest design. A phase 2 wks, B phase 6 wks. Initial pilot with TD adolescents.</td>
<td>n = 13. 6 dropped out. Analysis of 7 results only. Age 12–20 yrs.</td>
<td>3× per wk. Isotonic exs for trunk, hips/knees/ankles flexors/extensors, and hip abductors. 80% 1RM, 8–10 reps each. Free weights, weight machines, elastic bands, and body weight. Progressed by increased reps, then increased load. Stretches before and after each session. Maintained normal activities.</td>
<td>2 at local gym. 5 at school gym. Worked with peer helper at each session.</td>
</tr>
<tr>
<td>Study (Author and Year)</td>
<td>Design and Length</td>
<td>Subjects</td>
<td>Intervention: Frequency, Type, Resistance, Progression, Additional Activities</td>
<td>Setting</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------</td>
<td>----------</td>
<td>---------------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Engsberg et al, 2006</td>
<td>RCT</td>
<td>n = 15</td>
<td>3 X per wk&lt;br&gt;Isokinetic exs, 3 sets of 5 reps, each at 30°/sec and 90°/sec, each concentric and eccentric Load: 80% of max for each speed, progressed by machine&lt;br&gt;Group 1—dorsiflexor training&lt;br&gt;Group 2—plantarflexor training&lt;br&gt;Group 3—dorsi- and plantarflexor training&lt;br&gt;Group 4—no ST (controls)</td>
<td>Home town PT gym</td>
</tr>
<tr>
<td>Jiang et al, 2006</td>
<td>RCT</td>
<td>n = 20</td>
<td>3 X per day, 3 X per wk&lt;br&gt;Sit to stand (STS) with weighted vest&lt;br&gt;a. STS × 10, weights 20% 1RM&lt;br&gt;b. STS to fatigue, weights 50% 1RM&lt;br&gt;c. STS × 10 weights 20% 1RM&lt;br&gt;Progressed by retesting 1 RM every 2 wks&lt;br&gt;“Regular PT” for all subjects—passive movements, positioning, balance exs, functional training, NDT</td>
<td>Gym in rehabilitation dept</td>
</tr>
<tr>
<td>Liao et al, 2007</td>
<td>RCT</td>
<td>n = 24, randomized to 2 groups of 12&lt;br&gt;2 withdrew from each group&lt;br&gt;Mean age ST group 7 yrs 1mo, controls 7 yrs 7 mo. Referred by clinicians from several centers</td>
<td>3 X per wk&lt;br&gt;Diplegia/quadriplegia—bilat exs&lt;br&gt;Hemiplegia—unilateral exs&lt;br&gt;3 × 5 maximum effort knee flexion/extension, at 90°/sec&lt;br&gt;Progression: isokinetic machine gave greater resistance&lt;br&gt;Follow-up period: normal activities</td>
<td>ST at home, supervised by parents; fortnightly visit by researcher PT. Exercise diary. “Regular PT” weekly at treatment centre</td>
</tr>
<tr>
<td>MacPhail and Kramer, 1995</td>
<td>Single group, pretest/posttest design. 8 wks intervention, 12 wks follow-up</td>
<td>n = 17 mild CP&lt;br&gt;Age 12–20 yrs, mean 15.8 yrs&lt;br&gt;Ambulatory without aids. Mainstream education</td>
<td>3 X per wk&lt;br&gt;Isokinetic exs&lt;br&gt;Diplegia/quadriplegia—bilat exs&lt;br&gt;Hemiplegia—unilateral exs&lt;br&gt;3 × 5 maximum effort knee flexion/extension, at 90°/sec&lt;br&gt;Progression: isokinetic machine gave greater resistance&lt;br&gt;Follow-up period: normal activities</td>
<td>Gym, with PT</td>
</tr>
<tr>
<td>Morton et al, 2005</td>
<td>Single group, pretest/posttest design. 6 wks intervention, 4 wks follow-up</td>
<td>n = 8 ambulatory CP&lt;br&gt;GMFCS 3&lt;br&gt;Age 6yrs 10 mos–11 yrs 2 mos, mean 8 yrs 5 mos&lt;br&gt;7 of 8 used walking aids&lt;br&gt;7 of 8 used AFOs&lt;br&gt;Convenience sample</td>
<td>3 X per wk&lt;br&gt;Isotonic open-chain exs. Exercised quadriceps in sitting, hamstrings in prone lying&lt;br&gt;3 × 5 reps each muscle&lt;br&gt;Free weights—65% 1RM&lt;br&gt;Progressed by increased reps: 3 × 5, 4 × 5, 3 × 10&lt;br&gt;1RM reassessed every 2 wks, and load increased</td>
<td>PT gym of special school</td>
</tr>
</tbody>
</table>
studies found some improvement at least in dimension E and one did not report scores but approximately half the sample improved. One further study found significant improvement in 3 weight-bearing functional tests; where effect size could be calculated all favored treatment, but 3 of 6 studies showed small effects (Table 5).

Gait

Most studies assessed gait. Four studies used 3D gait analysis (3DGA) and found improvements in some gait parameters, although this was not always statistically significant. One study using visual gait analysis found similar results. Timed walking tests found mixed results and timed stair-climbing showed nonsignificant improvements. All studies favored treatment, with small-to-moderate effects (Table 5).

Subgroup Results

Preadolescent children showed large effects for strength and moderate effects for gait; adolescents also showed large effects for strength, but smaller effects for gait (Table 5). Subgroup results concerning clinical severity were mostly unidentifiable because of lack of individual or subgroup data in reports. Children with diplegia showed greater strength gains than those with hemiplegia in 2 studies, but no difference in 1 study. Two studies gave no diagnostic subgroup results. Subjects with diplegia comprised the entire sample in 7 studies.

Detraining

Reassessment after a period of detraining found isometric strength was maintained or slightly increased but isokinetic strength deteriorated (Fig. 1A). Function test results were maintained or slightly increased (Fig. 1B). Gait parameters showed a reduction of gains seen post-training, although these did not return to baseline levels (Fig. 1C). The length of detraining for these studies ranged from 4 to 12 weeks.

Other Results

No study found an increase in muscle tone; 2 found a significant decrease, as measured by an isokinetic dynamometer or by resistance to passive stretch on a myometer. A few mild adverse events were recorded which were mostly muscle or joint soreness. The most serious adverse event was development of knee hyperextension in 5 subjects who had previously had hamstring-lengthening surgery.

DISCUSSION

Quality of Included Studies

Quality scores indicate sufficient internal validity in more noncontrolled studies (5 of 7) than RCTs (2 of 5). The effects in the noncontrolled studies were mostly larger than in the RCTs, but in the same direction. It is acknowledged that a systematic review including more high quality
### TABLE 4

**Study Data—Outcomes**

<table>
<thead>
<tr>
<th>Study</th>
<th>Outcome Measures: Timing, Blinding, Measures Used</th>
<th>Results: For Each Outcome Measure</th>
<th>Main Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blundell et al, 2003&lt;sup&gt;29&lt;/sup&gt;</td>
<td>Baseline, 2 wks (end of A), 6 wks (end of B), 14 wks (end of A) Nonblinded 1. Isometric hip/knee/ankle flex + ext: handheld dynamometer 2. Lateral step-up test 3. Motor Assessment Scale sit-to-stand item 4. Min chair height test 5. Timed 10 m walk, with gait parameters 6. 2 min walk test 7. 9-hole peg test</td>
<td>Overall stable in A phase, improved in B, maintained in A 1. Sig overall increase; sig increase hip flex/ext, knee ext, right dorsiflexion ($p &lt; 0.025$) 2. Sig increased ($p = 0.001$) 3. Sig increased ($p = 0.014$) 4. Sig increased ($p = 0.002$) 5. Sig increased ($p = 0.049$); stride length sig increased ($p = 0.008$) 6. Nonsig increased ($p = 0.108$) 7. No change All improved measures maintained during second A phase. No sig correlation between isometric strength and any functional test. Moderate/high correlation between lateral step-up test and walk tests/sit-to-stand test</td>
<td>Functional (isotonic) ST program gave improved isometric strength and improved performance of walking and sit-to-stand, with results maintained at 8 wks follow-up</td>
</tr>
<tr>
<td>Damiano et al, 1995a&lt;sup&gt;30&lt;/sup&gt;</td>
<td>Baseline, 3 wks, 6 wks Assessor blinded to previous results 1. Isometric quads and hams, handheld dynamometer. Best of 2 trials, quads at 30°, 60°, 90° knee flex; hams at 90° only 2. 3DGA</td>
<td>Quads strength compared with controls at baseline: 37% of controls' strength at 30° flex, 53% at 60°, 69% at 90°. Hams strength 52% of controls 1. Quads sig increased strength at 90°, 60°, and 30° ($p &lt; 0.001$); greatest increase at 30° knee flex. Difference with controls became nonsig Hams nonsig increased strength ($p = 0.085$) Quads:hams ratio sig higher in CP subjects compared with controls ($p &lt; 0.001$), and moved higher still 2. Mod/strong inverse correlation between quads strength at 30° and degree of crouch. Positive correlation between quads and hams strength and gait velocity ($r = 0.60$)</td>
<td>Role of weakness in motor dysfunction in neurological disorders is still unresolved; but this study shows significant response to ST. ST needs further consideration as one component of PT for children with CP</td>
</tr>
<tr>
<td>Damiano et al, 1995b&lt;sup&gt;31&lt;/sup&gt;</td>
<td>Baseline, 6 wks 3DGA in bare feet: 3 trials at free speed, 3 at fast speed</td>
<td>Sig improvement in free speed knee flexion at heel strike, and in stride length at both speeds ($p &lt; 0.05$) Nonsig improved knee extension at stance, hip and knee excursion, gait speed—at both speeds</td>
<td>ST improved ambulatory ability in children with CP</td>
</tr>
<tr>
<td>Damiano and Abel, 1998&lt;sup&gt;32&lt;/sup&gt;</td>
<td>Baseline, 6 wks Assessor blinded to previous results 1. Isometric strength with handheld dynamometer—hip flex/ext, abd/add, knee flex/ext; ankle flex/ext. compared with TD data 2. GMFM 3. 3DGA: average of 3 trials, at free and fast speeds 4. EEI during gait, at free walking speed</td>
<td>1. Diplegia sig increased strength in targeted muscle, by 69%. Hemiplegia sig increase by 20% 2. Dimension E sig increased ($p &lt; 0.05$); subjects with hemiplegia may have showed a ceiling effect 3. Velocity and cadence increased at both speeds ($p = 0.01$) also reduced double support at fast speeds ($p = 0.02$) 4. No sig change</td>
<td>Short-term ST program has positive functional outcomes for ambulatory children with a spectrum of spastic CP</td>
</tr>
<tr>
<td>Dodd et al, 2003&lt;sup&gt;33&lt;/sup&gt;</td>
<td>Baseline, 6 wks, 18 wks Blinded assessor 1. Isometric strength hip and knee extensors, plantarflexors—handheld dynamometer. Practice test, then average of 2 tests 2. GMFM—D + E 3. Timed stair test 4. Self-selected walk speed—middle 10 m of 14 m walkway</td>
<td>1. Overall trend to increased strength in ST group. Stat sig increase in combined knee ext + plantarflex strength, at 6 wks and 18 wks ($p &lt; 0.05$). Overall maintained/increased strength at 18 wks 2. ST group nonsig improved GMFM-E at 6 wks ($p = 0.07$) 3. Nonsig improvement in ST group ($p = 0.10$) 4. Slight increase both groups</td>
<td>Home-based ST program can improve muscle strength in young subjects with spastic diplegia CP, and may be beneficial for walking, jumping, running and stair-climbing</td>
</tr>
</tbody>
</table>

(Continued)
### TABLE 4  
(Continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Outcome Measures: Timing, Blinding, Measures Used</th>
<th>Results: For Each Outcome Measure</th>
<th>Main Conclusions</th>
</tr>
</thead>
</table>
| Eagleton et al., 200434| Repeated measures over 2 wks baseline period; reassess at 8 wks Nonblinded 1. Isometric strength—handheld dynamometer—but eliminated because equipment failure  
2. Distance walked in 3 mins at free speed  
3. Visual analysis of gait at free speed—middle 6 m of 10 m walkway  
4. EEI—heart rate before and after 3 min walk | 1. No results  
2. Improved in 6 of 7 subjects; stat sig increase ($p = 0.05$)  
3. Stat sig improved gait velocity, step length, cadence ($p = 0.05$)  
4. Reduced in 4 of 7 subjects; stat sig decrease ($p = 0.05$) | 6 wk ST program effective in increasing distance walked in 3 mins, gait velocity, step length, and cadence; also in reducing EEI |
| Engsberg et al., 200635| Baseline, 12 wks Nonblinded 1. Isokinetic strength dorsi- and plantarflexors, at 30°/sec and 90°/sec, best of 3–5 trials  
2. Spasticity plantarflexors by stretch on isokinetic machine at 10°, 30°, 60°, 90°, 120°/sec  
3. Passive dorsiflexion range, standardized procedure  
4. GMFM full tool, converted to GMAE score. Also GMFM-E to account for possible ceiling effect of GMAE  
5. 3DGA  
6. PedsQL—function/participation questionnaire | 1. Trained muscle in each group sig increased eccentric strength at 30°/sec, 90°/sec ($p < 0.05$); and nonsig increased concentric strength. No sig changes for all untrained muscles  
2. Sig reduced spasticity in training groups ($p < 0.05$)  
3. Nonsig increase in dorsiflex training group, plantarflex training group. No changes in other groups  
4. No sig changes GMAE. Sig increase GMFM-E in training groups ($p = 0.041$); sig correlation between strength change and GMAE change ($p = 0.048$) in training groups, also between strength change and GMFM-E change ($p = 0.001$)  
5. Plantarflex and dorsi-plantarflex training groups increased gait speed and stride length. No sig changes other groups. Plantarflex group increased knee extension during gait  
6. Sig increase plantarflex and dorsi-plantarflex groups No sig change dorsiflex and control groups | Isokinetic ST gives increased strength, improved function, quality of life, and gait kinematics |
| Jiang et al., 200636 | 1. Passive range of movement knees, ankles  
2. Modified Ashworth Scale—spasticity  
3. GMFM-C + D + E  
4. Timed 10 m walk  
5. Distance walked in 1 min | 1. Sig improvement in training group at ankle ($p < 0.05$); no sig difference at knee  
2. No sig changes  
3. Training group sig improved ($p < 0.05$)  
4. Training group sig improved ($p < 0.05$)  
5. Training group sig improved ($p < 0.05$) | ST in children with CP can improve “moving ability,” walking ability and range of movement, without any adverse effects on spasticity |
| Liao et al., 200737 | Baseline, 6 wks One blinded assessor, at same time of day 1. Knee extensor strength—isometric manual muscle tester. Average of 3 trials  
2. IRM STS—standardized procedure  
3. GMFM-D + E  
4. Gait speed over 10 m, average of 3 trials  
5. PCI—heart rate during last 4 mins of 7 min walk at self-selected speed | 1. Nonsig increase—but controls also increased strength  
2. Sig increase ($p = 0.001$)  
3. Sig differences ST group versus controls ($p = 0.02$)  
4. Nonsig increase speed in ST group ($p = 0.18$)  
5. Sig improved ($p = 0.005$) | Weighted vest STS ST in children with mild spastic diplegia aged 3–12 yrs shows sig increased GMFM, IRM STS, and PCI |

(Continued)
<table>
<thead>
<tr>
<th>Study</th>
<th>Outcome Measures: Timing, Blinding, Measures Used</th>
<th>Results: For Each Outcome Measure</th>
<th>Main Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MacPhail and Kramer, 1995&lt;br&gt;38</td>
<td>Baseline, 8 wks, 20 wks. Each measure ×2, 1 wk apart, and averaged&lt;br&gt;Assessor blinding not stated&lt;br&gt;1. Isokinetic concentric/eccentric knee flex/ext—best of 2 of 3&lt;br&gt;2. GMFM-D + E&lt;br&gt;3. EEI at free and fast walk speed&lt;br&gt;4. Gait velocity over 3 mins, free and fast speeds&lt;br&gt;5. Muscle tone—Modified Ashworth Scale quads and hams; ankle clonus on 4-point scale, by experienced PT</td>
<td>1. Overall sig increased peak torque and work. Peak torque increased 25% at 8 wks, 17% at 20 wks. Work increased 21% at 8 wks, 15% at 20 wks (p &lt; 0.001)&lt;br&gt;2. Scores not given. Sig increase in 9 of 17 subjects (p = 0.011). No change in 7 of 17, decreased in 1 of 17&lt;br&gt;3. No sig change&lt;br&gt;4. No sig change&lt;br&gt;5. No sig change</td>
<td>ST is a viable treatment option, in conjunction with other interventions. Isokinetic ST is safe, effective means of increasing strength and improving standing walking running and jumping in subjects with mild CP</td>
</tr>
<tr>
<td>Morton et al, 2005&lt;br&gt;39</td>
<td>Baseline, 6 wks, 10 wks&lt;br&gt;Blinded assessor&lt;br&gt;1. Isometric strength – hand-held myometer. Practice, then mean of 3 trials. Quads, hams&lt;br&gt;2. GMFM-D + E&lt;br&gt;3. 10 m timed walk at free and fast speeds: mean of 3 trials&lt;br&gt;4) Muscle tone – resistance to passive stretch with hand-held myometer. Quads, hams</td>
<td>1. Sig increase mean muscle strength quads and hams, at 6 wks and 10 wks (p &lt; 0.01). Ratio quads:hams moved nearer normal&lt;br&gt;2. Trend for all scores improved. Sig improvement dimension E at 10 wks (p = 0.02)&lt;br&gt;3. Trend for improvement at 6 wks, regressed towards baseline at 10 wks&lt;br&gt;4. Reduced at 6 wks, sig reduced in left leg at 10 wks (p &lt; 0.04)</td>
<td>Free-weights ST is accessible, practical and safe method of increasing knee muscle strength and improving walking ability in ambulant children with spastic CP</td>
</tr>
<tr>
<td>Tweedy, 1997&lt;br&gt;40</td>
<td>2 measures before intervention and averaged; 2 measures after intervention and averaged&lt;br&gt;Assessor blinding not stated&lt;br&gt;1. Isokinetic strength quads at 80°, 65°, 50°, 35°, 20° extension&lt;br&gt;2. Isokinetic strength quads at 60°/sec&lt;br&gt;3. Flexibility—passive knee flex/extension, active knee extension&lt;br&gt;4. Muscle tone about knee—resistance to isokinetic movement at 60°, 40°, 20°, 12°/sec</td>
<td>1. Sig increase at 80°, 65°, 50° (p &lt; 0.05); increase became less for measures towards extension, non-sig at 20° extension&lt;br&gt;2. Sig increase in peak torque and work (p &lt; 0.01); also some increases between first + second preintervention measures, and between first + second postintervention measures&lt;br&gt;3. Sig improved passive flex right knee (p = 0.005); no sig differences all other movements&lt;br&gt;4. Sig decrease right leg resistance to passive movement at 60°/sec (p = 0.046); no other sig differences</td>
<td>Adolescent athletes with CP can achieve increased strength through ST program. No exacerbation of resting muscle tone. ST has a role in exercise programs of athletes with spasticity</td>
</tr>
<tr>
<td>Unger et al, 2006&lt;br&gt;41</td>
<td>Baseline, 8 wks&lt;br&gt;Blinded assessors&lt;br&gt;1. 3DGA in bare feet, at free speed, 3–8 trials&lt;br&gt;2. Self-perception questionnaire (developed by these researchers)</td>
<td>1. Stat sig improved sum of hip/knee/ankle angles at midstance, for ST group compared to controls (p = 0.03). No sig changes in stride length, velocity, cadence&lt;br&gt;2. Not relevant to this review</td>
<td>ST program targeting multiple muscle groups can lead to improved degree of crouch gait</td>
</tr>
</tbody>
</table>

abd indicates abduction; add, adduction; CP, cerebral palsy; EEI, energy expenditure index; ext, extension; flex, flexion; GMAE, Gross Motor Abilities Estimate (66 items from GMFM); GMFM, Gross Motor Function Measure (88 items); hams, hamstrings; min, minute; PCI, physiological cost index; PedsQL, Paediatric Quality of Life Inventory; PT, physiotherapy; reps, repetitions; quads, quadriceps; sig, statistically significant; ST, strength-training; STS, sit-to-stand; TD, typically-developing; 3DGA, three-dimensional gait analysis.
RCTs would produce more robust evidence, but given the paucity of RCTs in this clinical area the included noncontrolled studies are valuable. Their findings add strength to the body of evidence.

**Effect of Strength on Function and Gait**

An intervention should have an effect on the level of disability measured by activity and participation outcomes. Knee muscle strength is moderately and significantly correlated with GMFM scores and standing balance in children and young people with CP. Many neuromuscular and musculoskeletal deficits, however, interfere with motor function in CP and successful intervention depends on identifying which is the most limiting impairment. Impairments other than strength may have been significant as several included studies indicated that some subjects had previously had interventions for spasticity, soft tissue contractures, and bony deformities. Selective motor control is infrequently measured but was found to be significantly limiting in younger children. Teenagers may have more advanced soft tissue contractures and joint deformities that could limit improvements in gait and function, independent of muscle strength. The GMFM may have a ceiling effect in older subjects, thereby masking true

### TABLE 5
Within-Group Measures of Effect (Pre/Postintervention) in Subgroups by Age

<table>
<thead>
<tr>
<th>Strength Measures</th>
<th>Function Measures</th>
<th>Gait Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preadolescent Studies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blundell et al, 2003</td>
<td>1.622</td>
<td>0.778</td>
</tr>
<tr>
<td>Damiano and Abel, 1998</td>
<td>(Stat sig increased strength)</td>
<td>0.054</td>
</tr>
<tr>
<td>Jiang et al, 2007</td>
<td>(Not assessed)</td>
<td>0.363</td>
</tr>
<tr>
<td>Liao et al, 2006</td>
<td>0.875</td>
<td>0.727</td>
</tr>
<tr>
<td>Morton et al, 2005</td>
<td>0.95</td>
<td>(Trend for all scores improved)</td>
</tr>
<tr>
<td><strong>Adolescent studies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eagleton et al, 2004</td>
<td>(Equipment failure)</td>
<td>(Not assessed)</td>
</tr>
<tr>
<td>MacPhail and Kramer, 1995</td>
<td>0.797</td>
<td>(Sig improved 9/17 subjects)</td>
</tr>
<tr>
<td>Tweedy, 1997</td>
<td>0.800</td>
<td>(Not assessed)</td>
</tr>
<tr>
<td>Unger et al, 2006</td>
<td>(Not assessed)</td>
<td>(Not assessed)</td>
</tr>
<tr>
<td><strong>Mixed age group studies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damiano et al, 1995</td>
<td>2.780</td>
<td>(Not assessed)</td>
</tr>
<tr>
<td>Dodd et al, 2003</td>
<td>0.280</td>
<td>0.173</td>
</tr>
<tr>
<td>Engsberg et al, 2006</td>
<td>0.777</td>
<td>0.094</td>
</tr>
</tbody>
</table>

Fig. 1. (A) Effects of detraining on strength measures. (B) Effects of detraining on function measures. MacPhail and Kramer did not reassess function at follow-up; Morton et al found significant increase in GMFM-E at follow-up but gave insufficient data to calculate effect size. (C) Effects of detraining on gait measures. MacPhail and Kramer did not reassess gait at follow-up.
functional gains. As gait deterioration is common in teenagers with CP it may be that nonsignificant gains were clinically meaningful, in that subjects did not deteriorate. Here the intervention is fighting the natural course of the condition, whereas preadolescent children are likely to acquire motor skills and the strength training simply enhances this.

There may have been a ceiling effect in the more able subjects with hemiplegia. Strength training in adults following stroke showed variable carryover to function which was possibly partly due to compensation using the uninvolved side. If subjects with hemiplegic CP have developed compensatory ways of functioning, increased strength may not alter or normalize these. The involved side remains weaker than the uninvolved side, especially during short strength-training interventions. Subjects with diplegia are less likely to compensate in this way so weakness may be more clearly reflected in functional scores. The effect of strength on athletic performance in children who are developing typically is inconclusive. If the movement quality of subjects with CP is altered following training, the GMFM does not identify this.

It has been suggested that strength-training protocols should match functional tasks to facilitate learning but this was performed in only 3 studies. Motor learning is also influenced by an individual’s attitude, environment, and capacity to solve motor problems and harness abilities in different contexts. Carryover of strength gains to functional activities may not be immediate and 3 studies showed higher function scores at detraining follow-up. Strength gains may have allowed these children to practice improved functional activities without further training. Croce and DePaepe argue that children must learn an action to the point of automatic execution before it is incorporated into other activities, which could be related to the intensity and length of studies.

**Crouch Gait**

Three studies found significantly improved knee extension during walking. Crouch gait with excessive hip and knee flexion in stance is common in subjects with CP and deteriorates without intervention. During normal gait, the hip and knee extensors work in a shortened position. Isometric testing identified muscles of subjects with CP appear weaker when working at shorter lengths, they may collapse into crouch because they are unable to exert sufficient extensor force in the shortened position. It is unclear whether strength training can alter this length-tension relationship. One study of isometric open-chain strength training identified greater strength gains at the shortest quadriceps length, possibly because the free leg achieves greater knee extension during training without opposition by body weight. The quadriceps work therefore in their weaker shortened range where a training effect may then occur. One study found knee extension at heel strike significantly improved: the similarity of this gait action to the training action may account for this. A muscle, however, rarely functions in isolation; the incomplete carryover of strength to function and gait following open-chain exercising may be because of differences in the intensity, frequency, and range of motion used in the weight-bearing studies. Additionally, as isolated work at one joint is often difficult for children with spasticity, whole-limb activities may be more achievable.

Training should be specific regarding muscle length, peak force, activation patterns, timing, amplitude, and contraction type. The 2 isokinetic studies found little carryover to function and gait parameters; this indicates strength gained isokinetically may be less functionally useful, as isokinetic movement does not occur in everyday function. Closed-chain isotonic exercises however are similar to the gait parameters the intervention is designed to improve. If strength gains are initially due to improved neural activation, then the training effect from closed-chain exercise is more specific to gait and weight-bearing functions. Additionally Bobath suggested weakness may partly be attributable to tactile or proprioceptive sensory deficits and is counteracted by massive sensory stimulation. Electrical stimulation increases strength perhaps partly because it alters sensory inputs that affect the excitability of interneurones and motor neurones. Closed-chain strength training may enhance sensory inputs by stimulating the proprioceptors in weight-bearing tissues which may improve motor recruitment. Sensory input may also improve body image deficiency, thereby facilitating better voluntary control.

**Gait Velocity**

The crouched position is inefficient, which reduces gait velocity. Whereas, there is good correlation between strength and velocity in subjects who are developing typically, improved strength in subjects with CP can only increase velocity in the absence of other more limiting impairments. When subjects with CP walk faster, they tend to increase cadence rather than stride length and show increased pelvic excursion, but not increased knee and hip excursion. The child relies on proximal trunk muscles to propel the legs forwards, so improved leg strength may have limited effects on velocity. Significantly increased stride length may be indicative of reduced crouch or greater stability of the stance leg.

Most studies using the timed stair climb and timed 10 m walk or measuring maximum velocity walking as part of 3DGA found some improvement. These tests assess maximum-effort performance and may reflect the maximum-effort training protocol used. One study found no significant change in maximum gait velocity; this study trained younger subjects by resisted sit-to-stand exercise, which may not have sufficiently influenced activity of the lower limb extensors in an upright walking position.

The 2 or 3-minute walk test at a self-selected pace is more indicative of walking ability for everyday function. Four studies found significant improvement in velocity, but another 4 found no significant change. Subjects with CP expend 2 to 3 times the normal amount of
energy in walking, which causes excessive fatigue; they tend to select a velocity and cadence that minimizes this fatigue. \(^5\) Fatigue is identified as significant in many adults with CP \(^6\) and may be the most limiting factor in the walking test, indicating strength training may not adequately address this factor.

**Gait Abnormality**

Thelen et al.\(^7\) argue abnormal coupling of hip and knee moments indicates CP gait is inherently altered and is not simply a weaker form of normal gait. Steinwender et al.\(^8\) suggest that as the muscle activation pattern is abnormal, it may not be improved by strength training and it may even be reinforced. Farmer\(^9\) suggests gait in subjects with CP is immature rather than abnormal, as the muscle firing sequences are similar to those of infants developing typically, but not similar to those of children who are maturing. Weakness and contractures induce compensatory strategies, eventually producing a gait that is both altered and slower.\(^{59,69}\) The wide range of gait results at self-selected and fast velocities indicate subjects showed various abnormalities and compensations, so general conclusions cannot be drawn.

**Gait Deterioration**

The maintenance of walking into adulthood is a concern often voiced by parents, this may be influenced by many factors.\(^{66}\) Stride length reduces with age and double support increases.\(^5\) Joint deterioration is a significant factor in loss of walking, and the increased patellofemoral force induced by the crouched posture can cause chronic pain.\(^5,56\) The effort required for walking increases with increasing height and weight, which causes premature fatigue.\(^70,71\) Furukawa et al.\(^72\) found reduced coordination and stability because of deformity, spasticity and weakness, which explained the deterioration in walking ability of 18 children with CP aged 9 to 14 years. General fitness was not a significant factor. Loss of confidence also affects young people’s walking ability.\(^70\) Strength training could positively influence many of these factors by increasing stride length\(^20–31,34,35\) and joint excursion,\(^30,31,35\) and by decreasing double support\(^32\) and crouch.\(^30,31,35,41\) Psychological benefits were not examined by this review, but some evidence exists for increased self-confidence and self-esteem which may encourage young people to realize greater physical potential.\(^73\) Nevertheless, literature concerning gait in young people with CP lacks specific evidence about who is most susceptible to deterioration and why.\(^74\) Future research should examine factors predisposing to gait deterioration and the use of strength training in conjunction with other interventions to maximize retention of functional and gait abilities.

**Limitations of this Review**

Unpublished or nonindexed foreign-language studies may have been missed by the search strategy. These could be more likely to have negative results which would affect the review’s findings.\(^21,73\) Study comparisons were limited as not all measured the same variables; some data were insufficient and missing data were not requested from the authors. Some eligible subjects in other studies spanning the age-limit of 20 years were excluded, as authors could not be contacted for individual data within the parameters of this review. The MAL tool has face and content validity and interrater reliability, but no other established psychometric properties.\(^76\) This is in common with many quality assessment tools used in rehabilitation research. Although it was developed from 2 tools with well-established validity and reliability, the Jadad Scale\(^24\) and the Delphi List\(^25\), their psychometric credentials cannot be directly transferred to the new tool.\(^76\) The use of Operational Guidelines for this systematic review resulted in substantial interrater reliability of the MAL.\(^27\) Within-group effect size calculations enabled comparisons between all studies, but between-group calculations were not performed for the 5 RCTs. Incomplete age and diagnosis subgroup data limited inferences.

**CONCLUSIONS**

Isotonic strength training was associated with moderate-to-large strength and function gains which were maintained after detraining, and small-to-moderate gait improvements that partially deteriorated during detraining. Two studies found isokinetic training enhanced strength with less significant effects on gait and function and some loss after detraining. Strength training may enhance motor development in younger children; it may counteract deterioration in youth, where statistically nonsignificant results may be clinically meaningful. Strength training may ameliorate some aspects of gait in children and youth with CP in the absence of more limiting factors. Secondary impairments, particularly in postadolescent youth, may limit carryover of strength gains to gait and function. Subjects experienced no increased spasticity or other serious side-effects.

The 3 previous reviews of English publications\(^18–20\) concluded strength training in CP improves muscle strength but were inconclusive regarding gait and function. They included more heterogeneous populations than this review, but presented no subgroup results. Detraining effects were not discussed. This review is therefore in accordance with previous findings, following a wider language-inclusive search and analysis of more recent literature. This review concerns a narrower population, adds findings for subgroups and detraining effects, and contributes to knowledge regarding gait and function outcomes.

**REFERENCES**

2. Johnson A, corresponding author for Surveillance of Cerebral Palsy in Europe. Prevalence and characteristics of children with...


Appendix A: The Maastricht-Amsterdam List and the Operationalization Guidelines

This quality assessment tool was recommended by van Tulder et al. and incorporates the criteria proposed by Jadad et al. and Verhagen et al. The recommended list was updated by van Tulder et al. These articles are therefore used to define the operationalization of the tool.

Each criterion is scored yes/no/unclear; one point is awarded for “yes,” otherwise no points are awarded. The tool gives a maximum of 19 points for controlled studies and 14 points for other designs.

Patient Selection

a. Were the eligibility criteria specified? (Descriptive criterion) Statement of inclusion/exclusion criteria such that it is clear from what section of the overall cerebral palsy population the sample was drawn, and therefore to whom the study conclusions may be applied.

b1. Treatment allocation: was a method of randomization performed? (Internal validity criterion) “A method to generate the sequence of randomization will be regarded as appropriate if it allowed each study participant to have the same chance of receiving each intervention and the investigators could not predict which treatment was next. Methods of allocation using date of birth, date of admission, hospital numbers, or alternation should be not regarded as appropriate.”

b2. Treatment allocation: was the treatment allocation concealed? (Internal validity criterion) “Assignment generated by an independent person not responsible for determining the eligibility of the patients. This person has no information about the persons included in the trial and has no influence on the assignment sequence or on the decision about eligibility of the patient.” This should be stated, not assumed.

c. Were the groups similar at baseline regarding the most important prognostic indicators? (Descriptive criterion) ‘To receive a “yes,” groups have to be similar at baseline regarding demographic factors, duration and severity of complaints . . . and value of main outcome measure(s).’ There should be no statistically significant differences between the groups at baseline. Important prognostic indicators for this review would include age and severity of cerebral palsy.
Interventions

d. Were the index and control interventions explicitly described? (Descriptive criterion) The intervention(s) should be described such that the reader could repeat the study, assuming a reasonable level of knowledge as a pediatric physiotherapist.

e. Was the careprovider blinded for the intervention? (Internal validity criterion) "The reviewer determines if enough information about the blinding is given in order to score a "yes." As with criterion (e), blinding of subjects to the intervention is impossible in strength training studies, and all studies will score "no" for this criterion.

f. Were co-interventions avoided or comparable? (Internal validity criterion) "Cointerventions should either be avoided in the trial design or similar between the index and control groups."26 The study report should indicate this is the case, it should not be assumed. This should include a statement about other physical activities such as sports, as well as any activities provided as "therapy."

g. Was the compliance acceptable in all groups? (Internal validity criterion) "The reviewer determines if enough information about the compliance to the interventions is acceptable, based on the reported intensity, duration, number and frequency of sessions for the index intervention and control intervention(s)."26 Omission of data from subjects unable to complete the full training schedule implies full compliance of the remaining subjects, and scores "yes" (although this is not an intention-to-treat analysis and will score "no" for item p). Make-up sessions within a reasonable time frame will count as compliance, and contribute to a "yes." No statement about compliance with training sessions does not confer an assumed "yes," but will score "unclear."

h. Was the patient blinded for the intervention? (Internal validity criterion) "The reviewer determines if enough information about the blinding is given in order to score a "yes." As with criterion (e), blinding of subjects to the intervention being assessed . . . . could [not] identify the intervention being assessed."24 In the case of noncontrolled studies, blinding of the assessor to subjects’ previous scores will confer "yes" for this criterion. This should be stated, not assumed.

i. Were the outcome measures relevant? (Internal validity criterion) Any objective outcome measures evaluating change in functional abilities, gait parameters, gross motor abilities, and lower limb strength measures are regarded as relevant in this review. Outcome measures must be both validated and reliable. However, if the study relies solely on outcome measures devised by the authors for that study, with no/little evidence of validity or reliability, this scores “unclear.”

j. Were adverse effects described? (Descriptive criterion) Historically, many pediatric physiotherapists have believed strength training would cause the adverse effect of increased spasticity; and there could be a risk of musculoskeletal injury during strength training in children and youth, both disabled and non-disabled. Therefore, it is important that study authors report the occurrence, or absence, or any adverse effects. No statement about adverse effects scores “no.” A clear statement, be it positive or negative, scores “yes.”

k. Was the withdrawal/drop-out rate described and acceptable? (Internal validity criterion) "Participants who were included in the study but did not complete the observation period or who were not included in the analysis must be described. The number and the reasons for withdrawal in each group must be stated. If there were no withdrawals, it should be stated in the article. If there is no statement on withdrawals, this item must be given no points."24 ‘If the percentage of withdrawals and drop-outs does not exceed 20% for short-term follow-up and 30% for long-term follow-up and does not lead to substantial bias a “yes” is scored. (Note: these percentages are arbitrary, not supported by literature).’26

Outcome Measurement

i. Was the outcome assessor blinded for the intervention? (Internal validity criterion) "The reviewer determines if enough information about the blinding is given in order to score a “yes.”26 “The method will be regarded as appropriate if it is stated that . . . . the person doing the assessments . . . . could [not] identify the intervention being assessed."24 In the case of noncontrolled studies, blinding of the assessor to subjects’ pre-
the timing of the intervention. Staggered recruitment is acceptable, provided each subject is assessed at the same time points in relation to the intervention.

Statistics

o. Was the sample size for each group described? (Statistical criterion) Is the sample described such that the reviewer can envisage where in the population this sample comes from? This item requires the description of the sample, as distinct from the description of the population required for item (a).

p. Did the analysis include an intention-to-treat (ITT) analysis? (Internal validity criterion) “All randomized patients are reported/analyzed in the group they were allocated to by randomization for the most important moments of effect measurement (minus missing values) irrespective of noncompliance and cointerventions.”26 If no subjects were lost, no ITT analysis is necessary and this item scores “yes.” A description of any subjects lost to follow-up is not, however, the equivalent of ITT analysis. For noncontrolled studies, the inclusion of data from any noncompliant subjects is required to score a “yes” for this criterion.

q. Were point estimates and measures of variability presented for the primary outcome measurements? (Statistical criterion) For outcome measures, the median value, interquartile range, and maximum/minimum values should be presented as a box plot; or the mean value and standard deviation given if the data is normally distributed.27

<table>
<thead>
<tr>
<th>Items in the 14-point scale for scoring non-controlled studies22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient selection</td>
</tr>
<tr>
<td>Interventions</td>
</tr>
<tr>
<td>Outcome measurement</td>
</tr>
<tr>
<td>Statistics</td>
</tr>
</tbody>
</table>

APPENDIX B

Levels of Evidence and Grades of Recommendation for Treatment

<table>
<thead>
<tr>
<th>Type of Study</th>
<th>Level of Evidence</th>
<th>Grade of Recommendation for Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic review of RCTs</td>
<td>1a</td>
<td>A</td>
</tr>
<tr>
<td>Individual RCT with narrow</td>
<td>1b</td>
<td>A</td>
</tr>
<tr>
<td>confidence interval</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low quality RCT</td>
<td>2b</td>
<td>B</td>
</tr>
<tr>
<td>Case-series</td>
<td>4</td>
<td>C</td>
</tr>
</tbody>
</table>

Abbreviated from Centre for Evidence Based Medicine,28 as applied to this review.