

Functional Outcomes of Strength Training in Spastic Cerebral Palsy

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Objective: To determine clinical effectiveness of strength training in children with spastic cerebral palsy.

Design: Prospective before and after trial in which subjects participated in a 6-week strength training program. All received before and after isometric strength evaluation of eight muscle groups in both lower extremities with a hand-held dynamometer, 3-D gait analysis at free and fast speeds, administration of the Gross Motor Function Measure (GMFM), and assessment of energy expenditure during gait.

Setting: Pediatric rehabilitation center at a tertiary care hospital.

Patients: Eleven children met inclusion criteria for participation. Six had spastic diplegia, were limited community ambulators, and demonstrated less than 50% of normal muscle strength. Five had spastic hemiplegia and demonstrated a 20% strength asymmetry in at least two muscles across extremities.

Results: Each group had significant strength gains in the muscles targeted. The entire cohort had higher gait velocity primarily as a result of increased cadence, with greater capacity to walk faster. GMFM Dimension 5 also improved, with no change in energy expenditure. Asymmetry in strength improved in hemiplegia, with no change in asymmetry in support times or joint motion across extremities.

Conclusions: This study reinforced the relationship of strength to motor function in cerebral palsy and further demonstrated the effectiveness of strengthening in this population.

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WEAKNESS HAS LONG been recognized as a clinical characteristic in spastic cerebral palsy (CP), as implied by the names assigned to the types of CP such as quadriplegia, hemiplegia, and diplegia. This symptom, however, has rarely been addressed therapeutically in CP despite routine use of weight training in adult orthopedic patients and athletes. No scientific evidence exists to support the clinical prejudice against strength testing and training for individuals with CP or other upper motor neuron disorders. In fact, research findings are accumulating that indicate that children with cerebral palsy

are indeed weak,¹ that strength is directly related to motor function,^{1,2} and that isotonic and isokinetic strengthening programs can result in functional improvements. Documented positive outcomes from strengthening programs include increased stride length and decreased crouch during gait, greater energy efficiency when walking, and higher scores on the Gross Motor Function Measure (GMFM).^{3,4}

CP is caused by a static lesion to a developing nervous system that primarily affects motor function. The incidence of CP has remained fairly constant in recent decades at 2 to 3 per 1,000 live births, although the epidemiologic profile has shifted to include more children with spastic CP and fewer with extrapyramidal disorders.^{5,6} CP is a chronic central nervous system disorder for which no cure exists, nor is one imminent. Therefore, all current treatments, whether surgery, therapy, or medications, aim to alleviate such peripheral effects on the musculoskeletal system as muscle tightness and spasticity. Weakness is also a pervasive symptom in CP, and even highly functional ambulatory children with spastic diplegia and hemiplegia have been found to be weaker than normal in all major muscle groups of their affected lower extremities.⁷ Because strength has a direct relation to motor function in CP, children more motorically limited are assumed to be even weaker.

Weakness in CP has become more clinically evident in recent years because of the advent of selective dorsal rhizotomy (SDR). This neurosurgical procedure reduces spasticity while unmasking the underlying peripheral muscle weakness.⁸ Subsequently, strengthening exercises have been recommended after these procedures.⁹ Interestingly, preliminary results from a randomized trial comparing the efficacy of a physical therapy program incorporating strengthening with the efficacy of SDR plus an identical therapy regimen suggest that the strengthening program alone may be responsible for many of the positive outcomes.¹⁰

Not only can children with CP become stronger, they can also increase strength at a rate similar to persons with weakness who do not have a brain insult.¹ Previous studies have focused solely on knee musculature in ambulatory children and adolescents with mild to moderate spastic diplegia; hence, the clinical effectiveness of strengthening across multiple muscles and diagnostic categories in CP has yet to be established. In this study, the intention was to expand the exercise program to include more and different muscles selected on the basis of measurable weakness. In addition, we wanted to examine the effects within and across two distinct clinical subgroups: children with spastic hemiplegia and children with moderate to severe spastic diplegia. Nearly all children in both of these diagnostic categories are eventually ambulatory, although with variable difficulty.

Children with CP typically have decreased walking speed and less ability to increase velocity on demand than their able-bodied peers, with the magnitude of these deficits related directly to the degree of neurologic severity.^{11,12} Of the two parameters that comprise velocity, stride length tends to be relatively more limited than cadence in spastic CP.¹¹ However, the ability to compensate for restricted step length by heightened step frequency is increasingly less effective with greater

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motor involvement.¹² Even in ambulatory diplegia, motor ability can range considerably from highly functional independent walkers to children who require an assistive device at all times to ambulate. Joint motions during gait in the affected joints of the lower extremities are often diminished in comparison with normally developing children, with the exception of the ankle where either a pathologic limitation or exaggeration of motion may occur.¹³

Children with hemiplegia compensate well for their motor deficit, at the expense of asymmetrical development and use of the more involved extremity. Distal involvement is typically greater than proximal, but with increasing functional severity the proximal joints are progressively affected.¹⁴ Gait deviations noted in these children typically include a slight reduction in gait velocity, reduced step length and stance time on the more involved leg with a concomitant reduction in stride length, and reduced joint excursion and acceleration in comparison with the contralateral extremity.¹⁴ Strength values are diminished in children with hemiplegia when compared with age-matched peers, yet are typically higher than in children with diplegia.⁷

In this study, we hypothesized that a resistance training program would increase strength in the muscles targeted while values in the untrained muscles would not change. The untrained muscles were used as a basis for measuring the magnitude of the treatment effects. In the children with hemiplegia, strength changes in the targeted muscles on the more affected extremity were compared with the corresponding muscles on the contralateral extremity, and in diplegia the ipsilateral antagonist muscles were used as the untrained comparison. In the diplegic subgroup, we also wanted to examine the clinical concern that strengthening of the agonist would also increase strength in its spastic antagonist in CP because of excessive cocontraction or other neural mechanisms. Our second hypothesis was that subjects, regardless of diagnostic category, would demonstrate functional gains as a result of the program. For the children with hemiplegia, we additionally hypothesized that by correcting strength asymmetry through training of the more affected side, the asymmetric use of the extremities during gait, such as differences in the amount of joint motion, step lengths, and percent of support time across extremities, would likewise improve.

METHODS

Subjects

Eleven preadolescent children with CP ranging in age from 6 to 12 years (mean = 8.81 ± 2.32 yrs) participated in this study. All subjects were patients at a children's rehabilitation center and were required to be within the age range of 5 to 13, since children younger than 5 are less likely to consistently produce maximal effort and those older than 13, because of greater muscle mass, are more likely to produce forces greater than the limit of the hand-held dynamometer. A convenience sample was used and approximately 50 potential patients satisfying the age and diagnostic criteria were identified from the rehabilitation center's clinical database. Flyers were mailed to this list of potential participants, and volunteers subsequently contacted the Motion Analysis Laboratory by phone and were scheduled for an assessment in the order of response. An additional inclusion criterion for the children with hemiplegia was that they had to demonstrate at least a 20% asymmetry in strength values in a minimum of two of the eight muscle groups tested on their more involved extremity in comparison with the contralateral extremity. Additional restrictions for participation were also placed on the children with spastic diplegia. These

children needed to be at least moderately involved as determined by their status as a limited community ambulator¹² and they had to demonstrate at least 50% weakness from normal⁷ bilaterally in at least two of the eight lower extremity muscles tested.

The recruitment goal was a minimum of five subjects per diagnostic category, for a total of 10 subjects, a number determined to be sufficient for detecting significant strength changes within groups and functional effects for the entire cohort, based on a power analysis using the effect size from data collected previously in our laboratory (assuming 80% power with an alpha level of $p < .05$). The first six children with diplegia who were assessed met the inclusion criteria for participation, and were included in the study. Five of the six with hemiplegia met the criteria. The one child deemed ineligible demonstrated a 20% asymmetry in strength in only one muscle group. This protocol was approved by our university's Human Investigations Committee, with informed consent obtained from the responsible family member for each child.

Procedures

Each child had an initial strength evaluation that consisted of measurement of maximum isometric strength in eight muscle groups in both lower extremities using a hand-held dynamometer. Test positions were standardized and the following muscle groups were evaluated bilaterally: hip flexors, extensors, abductors, and adductors, knee flexors and extensors, and ankle dorsiflexors and plantarflexors (table 1). Absolute strength values in Newtons were recorded and used in the analyses. Additionally, the values for each subject were normalized by the individual's body weight. The percent of normal strength for each muscle was computed based on data obtained from our laboratory from 16 preadolescent children (mean age = 8.2 ± 2.4 yrs with a range of 5 to 12 yrs) with no history of motor pathology affecting either of the lower extremities tested in the identical manner.⁷ The rationale for this comparison was the fact that the muscles of the lower extremity produce varying amounts of force based on size and fiber architecture; therefore, absolute strength values alone provide no information on how weak a muscle is unless related to some standard. For the children with hemiplegia, the percent of strength asymmetry between the corresponding muscle group on the affected versus the unaffected extremity was calculated as well. This information was used to determine if the child met the strength criteria for participation. If so, the assessment procedure continued with the administration of the Gross Motor Function Measure (GMFM), computerized gait analysis, and assessment of energy expenditure during gait using a heart rate telemetry system.

The GMFM is a validated instrument designed to assess motor status in CP and to quantify change over time or as a result of intervention.¹⁵ It consists of 88 items within five dimensions that span the range of activities that most individuals encounter in daily activities: (1) lying and rolling; (2) sitting; (3) crawling and kneeling; (4) standing; and (5) walking, running, and jumping. Scores are expressed as a percentage so that a normally developing 5-year-old child would score 100%, and separate scores can be computed for each of the five dimensions as well as a total score.

Computerized gait analysis, including capture of three-dimensional kinematic data at freely selected and fast walking speeds, was performed using a Vicon 370 system, and data were processed using Vicon Clinical Manager software.⁸ For the gait analysis, passive markers were taped or secured with nonadhesive wrap on the following anatomic locations of both lower extremities: the anterior superior iliac spines, the sacrum,

Table 1: Standardized Muscle Test Positions

Muscle Groups	Body Position	Joint Position
Hip Flexors	Sitting	Hip flexed 30° off surface; resistance given anterior mid thigh.
Hip Extensors	Prone	Knee flexed 90° and thigh extended off surface; pelvis stabilized; resistance given posterior mid thigh.
Hip Abductors	Supine	Hip in neutral in all planes; lower extremities held slightly off surface; pelvis stabilized; resistance given lateral mid thigh.
Hip Adductors	Supine	Hip in 15° abduction; opposite leg flexed; lower extremities held slightly off surface; pelvis stabilized; resistance given medial mid thigh.
Knee Flexors	Sitting	Knee flexed 90°; resistance given posteriorly 2 inches proximal to lateral malleoli.
Knee Extensors	Sitting	Knee flexed 90°; resistance given anteriorly 2 inches proximal to lateral malleoli.
	Sitting	Knee flexed 30°; stabilized at thigh; resistance given anteriorly 2 inches proximal lateral malleoli.
Plantarflexors	Supine	Knee flexed 90° and resting on a bench; lower leg stabilized; resistance given across metatarsal heads.
Dorsiflexors	Supine	Knee flexed 90° and resting on a bench; lower leg stabilized; resistance on dorsum of foot at level of metatarsal heads.

the lateral aspect of the mid thigh, the knee and the mid calf, the lateral malleolus, the base of the heel, and the dorsal aspect of the foot between the second and third metatarsals. The child was then instructed to walk barefoot at a freely selected speed down a 12-meter carpeted walkway. The child was asked to walk independently if possible, but was allowed to use an assistive device if necessary. The children who were not visibly or reportedly fatigued after the free walking trials were asked to walk several more times with the instruction "as fast as possible without running," as a further challenge to their walking capabilities. A minimum of three trials were captured, processed, and averaged for each child in each condition.

In addition, an assessment of energy expenditure during walking at a self-selected pace was performed using a Polar Electro system^b by which heart rate was monitored and recorded during a 5-minute quiet rest period and a 5-minute continuous walking period. Heart rate is an accurate and convenient measure of energy expenditure during submaximal work in normally developing children and in children with CP and other developmental disabilities.¹⁶ Heart rate data from the last minute of each period were used in the analyses. An energy expenditure index (EEI) was computed for each child by subtracting the steady state walking heart rate from the resting heart rate, divided by the individual's mean gait velocity.¹⁷ The normal EEI value for a preadolescent child walking at a comfortable speed is reported to be $.47 \pm .13$ beats/min.¹⁶ Therefore, EEI values greater than .60 beats/min are considered above the normal range and indicate higher than normal energy expenditure, and a decrease in the EEI value as a result of an intervention is a desired functional outcome.

An identical comprehensive assessment was performed after completion of the 6-week strength training program described below. The same examiner performed all strength and motor assessments at both time points. In addition, the examiner did

not review or have access to pretraining strength values at the posttraining assessment.

The isometric strength data were also used to select the muscle groups for strength training. Generally, the two weakest muscles, as averaged across extremities, were identified for each child with diplegia for strengthening. Exceptions were made in three of the children with diplegia. In these children, the ankle dorsiflexors were the second weakest muscle group, but were not chosen for the strengthening program because a fixed contracture was present at the ankle joint in one child, or because the requirement to wear rigid ankle foot orthoses full-time in the other two children would have effectively negated any potential positive functional effects from strengthening of that muscle. For the children with hemiplegia, a minimum of two with a maximum of three muscles that showed more than 20% asymmetry across extremities were identified and then targeted for the strength training program.

The child and the responsible family member were instructed to perform the exercises. All children were asked to exercise three times a week for 6 consecutive weeks, allowing at least 1 day's rest between sessions. Velcro-attached free weights were used, and the load for each muscle was approximately 65% of the maximum isometric strength value determined for that muscle. Each child performed 20 exercises for each muscle group, in four sets of five repetitions each. Children with diplegia exercised bilaterally, whereas those with hemiplegia exercised unilaterally. Children were evaluated every 2 weeks to measure strength in the targeted muscle groups. Although the percent load remained constant throughout the program, the weight lifted was increased proportionately with strength gains. The therapist (DLD) supervised the initial, the 2-week, and the 4-week strength assessments and exercise sessions. A responsible family member supervised the remaining 15 sessions, and a

Table 2: Descriptive and Initial Assessment Data for All Subjects

Diagnosis	Age (yr)	Amb* Status	Muscles Trained	Velocity (m/sec) [†]	GMFM (%)	EEI	Left Strength	Right Strength	Mean Strength
Diplegia	9	3	B HF, KE	.39	61.1	2.8	40.6	32.8	36.7
	6	3	B HF, KE	.61	71.9	2.0	49.3	52.7	51.0
	12	2	B HF, KE	.93	89.4	1.2	26.3	26.7	26.5
	10	3	B HE, KE	.09	42.1	9.5	30.7	29.0	29.9
	6	3	B HF, KE	.84	58.2	4.4	31.3	28.3	27.8
	7	3	B HF, HABD	1.09	62.4	2.5	57.8	56.3	56.8
	11	1	R KE, PF, DF	1.22	98.1	0.2	62.2	55.3	58.8
Hemiplegia	6	1	R KE, DF	2.04	97.3	1.1	97.0	70.1	83.6
	11	1	R KE, KF, DF	1.45	96.9	0.8	66.3	50.8	58.6
	8	1	L KE, DF	1.80	97.3	0.6	68.2	67.8	68.0
	11	1	R KE, DF	1.85	94.9	1.0	48.6	34.4	41.5

Values in **bold** indicate affected side in hemiplegia. Strength values expressed as percent of normal.

Abbreviations: HF, hip flexors; HE, hip extensors; HABD, hip abductors; KE, knee extensors; KF, knee flexors; PF, plantarflexors; DF, dorsiflexors; R, right; L, left; B, bilateral.

* Ambulatory status: 1, independent ambulator; 2, uses an assistive device some of the time; 3, requires an assistive device for all ambulation.

[†] Velocity normalized by individual leg length in meters.

Table 3: Pearson Correlation Values Between Mean Strength and Functional Measures

Mean Strength With	<i>r</i>	<i>p</i>
Normalized velocity	.71	.02*
Stride length	.56	.09
Cadence	.63	.04*
GMFM total	.59	.05*
EEl	-.54	.09
Double support %	-.52	.10

* *p* < .05.

written log was maintained with the date, exercises performed and the number of repetitions recorded after each session.

Data Analysis

As an estimation of mean strength in the lower extremities for each child, a percent of normal strength for the eight muscles tested on each lower extremity was computed and then averaged to obtain a mean for each extremity and a combined mean of both extremities (table 2). The combined mean of the two extremities was then used to investigate the relation of strength to other functional parameters in CP using Pearson *r* correlation procedures. A stepwise multiple regression procedure was also performed to determine which functional measures best predicted strength in CP. The change in functional parameters as a result of the strengthening program was assessed using repeated measures analysis of variance (ANOVA) procedures. The changes in strength of the agonist and the antagonist muscle groups in diplegia and the affected and unaffected muscle groups in hemiplegia before and after training were also assessed using repeated measures ANOVA procedures. A significance level of *p* < .05 was used in all analyses.

RESULTS

Although varying degrees of involvement are seen in each diagnostic group, all subjects in the diplegia category had slower normalized velocity (divided by leg length), a lower GMFM total score, and less efficient gait pattern (higher EEl) than any of the subjects in the hemiplegia group (table 2). The six children with spastic diplegia were all limited community ambulators with five of the six requiring hand-held aids to ambulate at all times. The five children with hemiplegia were independent community ambulators. The mean strength of four of the five children with hemiplegia was greater than that for all six of the children with diplegia.

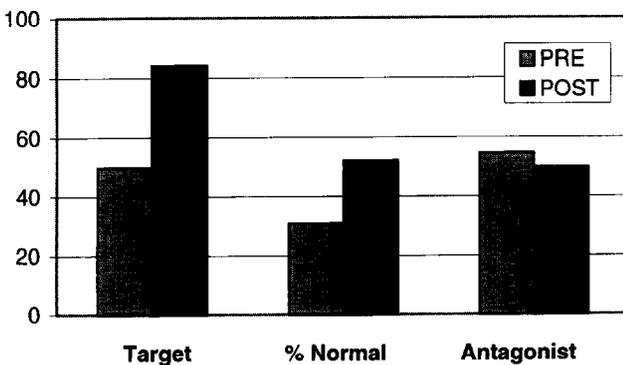


Fig 1. Change in mean strength of target muscles and their antagonists (*n* = 24; force measured in Newtons) and change in percent of normal strength for the target muscles (expressed as a percent) in the diplegia group before and after the strengthening program.

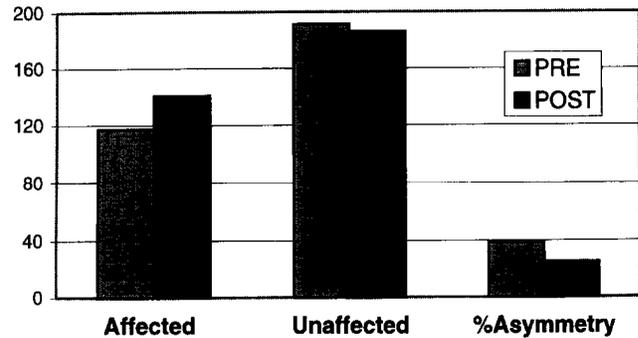


Fig 2. Change in mean strength of target muscles on affected side compared with corresponding muscles on unaffected side (*n* = 12; force measured in Newtons) and the change in strength asymmetry (expressed as a percent) in the hemiplegia group before and after strengthening program.

Correlations between initial mean strength and functional motor parameters show that children who were stronger tended to exhibit higher velocity and cadence and greater overall gross motor function (table 3). In the stepwise multiple regression analysis where strength was the dependent variable and the same six parameters listed above were entered as predictor variables, normalized velocity was shown to best predict strength and alone accounted for 50% of the variance in the mean strength value.

Statistical comparisons in the diplegia group indicated that strength did increase significantly after training in the targeted muscles by 69% (fig 1). The strength values of the antagonist muscles in the diplegia group showed an overall mean decrease (-9.0%) that was not significant. However, for the five children who strengthened the hip flexors, hip extensor strength did diminish significantly, with a loss of 21% from the pretraining recorded values. Although the children with diplegia had substantial strength gains, they demonstrated only 51% of normal strength values in the targeted muscle groups at the end of the 6-week program.

Statistical comparisons in the hemiplegia group revealed that strength did increase significantly on the more affected side by 20.3% with virtually no change (-2.7%) noted on the less affected side (fig 2). Percent asymmetry in strength also improved significantly; however, a 24% asymmetry across extremities still persisted.

To examine the functional changes from strength training in CP, the before and after strength training assessment values were compared for the entire cohort (table 4). Velocity and cadence increased significantly, as did the GMFM score on Dimension 5 (walking, running and jumping). The mean EEl did not change appreciably; however, children who had greater improvements in velocity tended to have worsening efficiency, whereas those with minimal or smaller changes in velocity tended to have improved efficiency (*r* = .64; *p* = .03). Even more marked changes in function were seen when the children were challenged to walk at their fastest speeds. Only 7 of the 11 children were able to complete the fast walking trials at both assessment points (all 5 children with hemiplegia and 2 with diplegia). As a result of the training, subjects were able to increase their maximal speed and this increase in velocity was achieved primarily by increased cadence. Double support percent, with lower values typically indicative of greater stability in stance, decreased significantly at the fast speed.

Although all five children with hemiplegia had greater than

Table 4: Changes in Functional Parameters for All Subjects Before and After Training

Parameters	n	Before	After	F	p
Velocity—free (m/sec)	11	.72 ± .49	.80 ± .42	11.2	.01*
Stride length—free (m)	11	.80 ± .23	.82 ± .25	3.64	.09
Cadence—free (steps/min)	11	99.5 ± 36.5	107.8 ± 35.7	7.49	.02*
% Stance—free (% gait cycle)	11	64.9 ± 8.80	63.6 ± 6.00	1.35	.27
% Double support—free	11	30.3 ± 17.7	28.1 ± 14.9	2.41	.15
Velocity—fast	7	1.50 ± .36	1.67 ± .41	18.2	.01*
Stride length—fast	7	1.14 ± .22	1.17 ± .25	4.90	.07
Cadence—fast	7	156 ± 21.0	169.6 ± 21.5	20.9	.01*
% Stance—fast	7	56.5 ± 3.90	54.9 ± 1.60	1.36	.30
% Double support—fast	7	12.7 ± 2.30	10.6 ± 3.10	11.4	.02*
GMFM Total (%)	11	79.1 ± 20.4	80.2 ± 20.4	2.59	.14
GMFM 5 (%)	11	53.3 ± 38.7	55.0 ± 40.0	5.88	.04*
EEL (beats/min)	11	2.37 ± 2.48	2.14 ± 2.40	.92	.27

* $p < .05$.

20% strength asymmetry across extremities in at least two muscles, the pretraining asymmetry in gait parameters was minimal. The only consistent feature was a slightly higher stance percent on the less affected side during free walking that became more pronounced during fast walking. In children with hemiplegia, step length asymmetry was unpredictable. The mean absolute value of the asymmetry was 5cm at the free speed and 4cm at the fast speed; however, for three of five subjects greater step lengths were seen on the more affected side and for the remaining two, step lengths were shorter on that side. The training program did not appreciably alter the pattern or magnitude of differences in support times or step lengths across extremities in any of the subjects at either gait speed (figs 3 and 4). Patterns of asymmetry in joint motion during gait were also inconsistent. Three of the five had greater motion in the more affected knee in comparison with the less affected extremity, and two had greater motion in the more affected ankle, only one of whom had higher knee motion on that side as well. However, the mean absolute value of asymmetry in knee or ankle motion did not change significantly after training.

DISCUSSION

Strength is an important aspect of normal motor control that has been shown to be deficient in CP and in other upper motor neuron diseases. This project reinforces the strong relation of strength to functional parameters in this population and provides

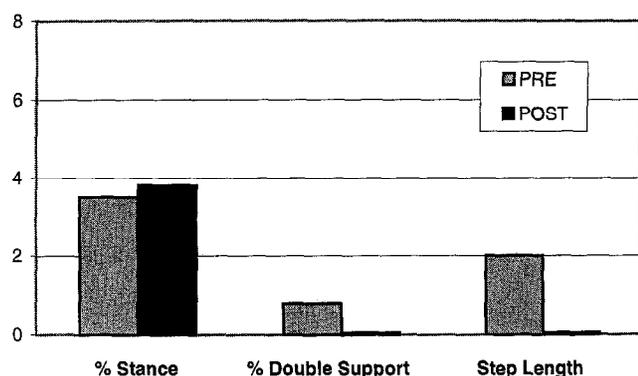


Fig 3. Asymmetry in free speed gait parameters in hemiplegia group before and after strengthening program with stance and double support expressed as difference in percent and step length as difference in centimeters across extremities. Bar above the line indicates unaffected side has higher value.

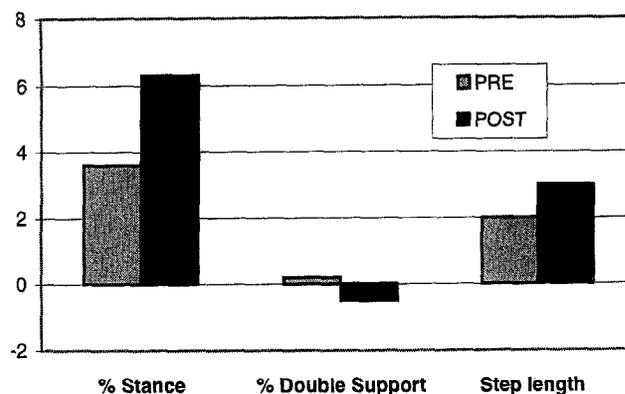


Fig 4. Asymmetry in fast speed gait parameters in hemiplegia group before and after strengthening program with stance and double support expressed as difference in percent and step length as difference in centimeters across extremities. Bar above 0 line indicates unaffected side has higher value.

further evidence that even in a diverse group of patients strength can be increased through training, thereby producing measurable clinical improvement.

Improvements after strength training are particularly evident in gait function. Muscle strength has already been shown to be highly correlated with gait velocity in adults recovering from strokes, and is more highly related to functional status than other clinical symptoms such as spasticity in those patients.¹⁸ Strength is correlated with overall gross motor function, but since the training was restricted to the lower extremities and did not involve the trunk and upper extremities, the improvements seen in the GMFM (Dimension 5 only) were mainly related to skills that involved lower extremity strength such as walking. It is likely that skills tested in the other four dimensions were either not as dependent on lower extremity strength or, if so, perhaps did not require the level of strength in those muscles as needed for ambulatory function. The children with hemiplegia also may have dampened the GMFM results since their scores were sufficiently close to maximum prior to the exercise program so as to produce a "ceiling" effect. Perhaps a more physically challenging assessment tool would be required to measure gross motor change in those subjects with higher motor abilities.

The effect of increased strength on gait also seems fairly specific in that it increases free walking velocity and the capability to walk faster almost exclusively through increasing cadence. A moderately strong relation between strength and cadence was uncovered in the correlation of preassessment values, and the results after the training program suggest a causal relation exists between these variables. Because of the relationships uncovered here, we can assume that the limited ability to compensate for restricted stride length by increasing cadence in CP is at least partly amenable to treatment such as strengthening regimes. Since most of the children still had substantial residual weakness after the 6-week training, potential further improvements in cadence and velocity could be achieved by continuation of the strengthening program.

In contrast to cadence, stride length in CP was not shown to be related to strength in this study. Restricted stride length in CP is largely the biomechanical effect of limitation in passive and active motion caused by spasticity, inadequate muscle length, or abnormal dynamic activity. Orthopedic muscle lengthening surgery improves passive range of motion directly

and has also been shown to increase velocity primarily by increasing stride length while cadence shows minimal change.¹⁹ Increasing velocity primarily through an increase in stride length produces greater energy efficiency during gait.¹⁶ Therefore, since the converse mechanism for increasing velocity was observed here, it was not surprising that no change was noted in the EEI as a result of training. An interesting correlation noted here showed that children who increased their velocity more after the strengthening program tended to be less efficient than before strengthening, indicating that their heart rate had not yet accommodated to this new higher level of activity, whereas children who had minimal increases in velocity tended to have improved efficiency. Possible explanations for lower EEI in those subjects include improved mechanical efficiency in the target muscles as a result of training, or more effective movement patterns.

Several explanations exist for the difference noted in the magnitude of strength increases across functional groups. Because the percent change is affected by the denominator, the initially weaker muscles in diplegia would be more likely to exhibit a greater percent change. However, the absolute gain in strength was also greater in that group, with a gain of 34.5 Newtons/muscle in the diplegia group and 22.7 Newtons/muscle in the hemiplegia group. It has been reported previously that relatively weaker muscles, as seen in the diplegia group, tend to respond to a greater degree than those closer to normal values.¹ It is also possible that children with diplegia maintained their strength gains more easily because the training was bilateral and was reinforced through reciprocal use of their extremities. Children with hemiplegia exercised unilaterally while continuing to rely more heavily on their stronger side. Therefore, reinforcing the strength gains through daily activity may have been less effective in this group. A logistic problem that also lessened the potential strength increases in hemiplegia was the fact that two of the children reached the maximum weight that could be placed on the foot by the 4-week assessment, so their strength gains in that muscle effectively plateaued at that point. To be able to provide sufficient resistance to the dorsum of the foot, velcro weights are insufficient for some children and a different method of applying load such as a pulley and weight system would need to be devised for future applications.

Although strength asymmetry did improve in the hemiplegia group, it was still greater than 20% in the muscles targeted. A 10% asymmetry in strength is considered clinically and functionally significant in orthopedic patients.²⁰ Therefore, it is possible that until the strength asymmetry is corrected, perhaps no appreciable alteration in functional asymmetry could be expected. Even if strength asymmetry were corrected, differences in spasticity and passive muscle length would still persist across extremities, and it is unknown to what extent weakness or these other factors contribute to asymmetry in motion and stability in hemiplegia. Yet another consideration is that because of long-standing motor patterns, children with hemiplegia may require additional functional training to maximize the effects of strength gains. It must be re-emphasized, however, that although asymmetry did not change, generally improved stability and increased cadence were seen in these subjects, particularly at the fast speed.

No child in the study deteriorated in function as a result of the training, and only a few transient complaints of mild muscle soreness were reported throughout the project. Since it has been documented that children with CP use excessive muscle cocontraction during voluntary movement,²¹ a clinical concern is the potential for inadvertent strengthening of the spastic antagonist

muscle during training of the agonist through persistent cocontraction or other neural mechanisms. This concern does not appear to be justified, as shown by a study that found no change in hamstring strength as a result of strengthening the quadriceps.³ In this study, hamstring strength again did not change in the children with diplegia who exercised their quadriceps. Hip extensor strength did decrease significantly in those who exercised their hip flexors, but the loss of strength in the untrained antagonist was considerably less than the gain in the agonist. One explanation for this may be negative transfer from a motor learning perspective, but the nonfinding at the knee joint argues against this. Nevertheless, this consistent finding was disconcerting and suggests that perhaps consideration should be given to concurrent hip extensor strengthening when addressing hip flexor weakness.

CONCLUSION

In summary, short-term strength training programs demonstrate positive functional outcomes for children with spastic CP across diagnostic categories and a wide spectrum of involvement in the ambulatory population. The effects of strengthening programs of longer duration or of combining strength training with interventions that address other clinical symptoms in CP such as muscle shortening or spasticity still must be explored. Furthermore, it is presumed that children with CP who are nonambulatory are even weaker and could also benefit from this type of exercise, although the functional goals would be considerably different in that sub-population.

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