

Functional strength training in cerebral palsy: a pilot study of a group circuit training class for children aged 4–8 years

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Received 2nd November 2001; returned for revisions 26th February 2002; manuscript accepted 18th July 2002.

Objective: To determine the effects of intensive task-specific strength training on lower limb strength and functional performance in children with cerebral palsy.

Design: A nonrandomized ABA trial.

Setting: Sydney school.

Subjects: Eight children with cerebral palsy, aged 4–8 years, seven with diagnosis of spastic diplegia, one of spastic/ataxic quadriplegia.

Intervention: Four weeks of after-school exercise class, conducted for one hour twice weekly as group circuit training. Each work station was set up for intensive repetitive practice of an exercise. Children moved between stations, practising functionally based exercises including treadmill walking, step-ups, sit-to-stands and leg presses.

Main outcome measures: Baseline test obtained two weeks before training, a pre-test immediately before and a post-test following training, with follow-up eight weeks later. Lower limb muscle strength was tested by dynamometry and Lateral Step-up Test; functional performance by Motor Assessment Scale (Sit-to-Stand), minimum chair height test, timed 10-m test, and 2-minute walk test.

Results: Isometric strength improved pre- to post-training by a mean of 47% (SD 16) and functional strength, on Lateral Step-up Test, by 150% (SD 15). Children walked faster over 10 m, with longer strides, improvements of 22% and 38% respectively. Sit-to-stand performance had improved, with a reduction of seat height from 27 (SD 15) to 17 (SD 11) cm. Eight weeks following cessation of training all improvements had been maintained.

Conclusions: A short programme of task-specific strengthening exercise and training for children with cerebral palsy, run as a group circuit class, resulted in improved strength and functional performance that was maintained over time.

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Introduction

Impairments affecting muscle strength and motor control are major causes of motor performance deficits in children with cerebral palsy.¹⁻⁴ These impairments, together with adaptive changes at neural and musculoskeletal levels, disturb muscle and bone growth and the learning of motor skills. Consequently, children learn to move in stereotyped ways imposed by reduced and disordered muscle force generation, increased muscle stiffness and soft tissue contracture.⁵

In neurological physiotherapy, the dominant clinical model, Neurodevelopmental (NDT) or Bobath Therapy, has long cautioned against muscle strengthening exercises, with the assumption that the effort involved would increase spasticity, co-contraction, associated reactions and abnormal movement patterns.^{6,7} The validity and effectiveness of this therapy that originated five decades ago is increasingly being questioned⁸ and more recent times have seen the development of a newer model for movement rehabilitation in adults and children. This model is based on recent investigations into impairments and adaptations associated with brain lesions and research findings in the fields of motor learning, motor control, biomechanics and exercise science.^{9,10} The focus is on the training of motor control with skill and flexibility of performance as goals, on the prevention of negative soft tissue adaptations, and on increased strength, endurance and physical fitness.

Several studies of children provide evidence in support of this training and exercise approach. Investigations of the effects of exercises for lower limb muscles have demonstrated increases in strength and function in children with cerebral palsy,¹¹⁻¹³ and in physical fitness,¹⁴ with no evidence of increases in spasticity or abnormal movements.^{11,13,15,16} These positive results are in agreement with several studies of adults following stroke.^{17,18}

In studies of children, the resulting increases in function were not as great as would be expected given the large gains in isometric muscle strength achieved. The methods of strength training examined in these studies have involved open-chain (non-weight-bearing) isokinetic¹¹ or isotonic exercises using free weights.^{12,13} Since strength-

ening effects are specific to the mode of training,¹⁹ nonweight-bearing exercises may have limited transferability to actions that are weight-bearing and involve different and more complex patterns of muscle activation. Gains in strength may transfer better into improvements in functional motor performance if strengthening exercises involved the practice of more functionally related closed-kinetic-chain exercises. In these exercises the subject is weight-bearing through the feet, and the body mass is raised and lowered over the feet by concentric and eccentric action of lower limb muscles, characteristics found in many activities involving the lower limbs, such as sit-to-stand and walking.

The aim of this pilot study was, therefore, to examine the effects of a four-week lower limb exercise programme on the motor function of young children with cerebral palsy. A secondary aim was to test the feasibility of a programme presented as a group circuit training class. This relatively novel method of delivery has been proposed for adults with neural lesions^{9,10} and has been found to have positive effects following stroke.²⁰ No studies have yet evaluated the effect of this type of programme, conducted in a group or otherwise, in children with cerebral palsy.

Methods

Subjects

A convenience sample of eight children (seven male, one female), aged from 4 to 8 years old (mean 6.3 years, SD 1.3), were invited to participate in the study. Seven of the children had a diagnosis of spastic diplegia, one was diagnosed as spastic/ataxic quadriplegia but had principally lower limb involvement. Five subjects were below their corresponding 25th percentile for height and age, and three others were below the 25th percentile for weight and age.²¹ Subjects were excluded from the study if they were known to be cognitively impaired, if they were nonambulatory, or if they had an orthopaedic or medical condition that prevented them from exercising. All children had received previous physiotherapy since early childhood. None attended physiotherapy during the duration of the study. Children and parents gave their con-

sent to the study and approval was obtained from the ethics committees of the University of Sydney and the Spastic Centre of NSW.

Design

The study employed a nonrandomized ABA design consisting of four measurement sessions. A baseline measurement was followed two weeks later by a pre-test carried out before the start of the training period. Training was conducted in one-hour sessions twice a week for four weeks after school. Immediately after the training period, subjects were retested, with a follow-up test taken eight weeks later. Conditions and procedures, including the order of the tests, were standardized across all measurement sessions.

Procedures

Strength tests

Isometric strength of hip, knee and ankle flexors and extensors was assessed using a hand-held dynamometer in gravity-independent positions²² utilizing a 'make' test.²³ Tests on each muscle group were repeated until the child gave three consistent results, with the constraint that there would be no more than six trials on any one muscle group. Lower extremity functional strength was tested with the Lateral Step-up Test, the number of step-ups performed in 15 seconds. This test is used as a measure of overall functional lower limb strength²⁴⁻²⁶ since it reflects factors such as balance, speed of movement and endurance as well as muscle strength.

Functional motor performance

This was tested using the Motor Assessment Scale sit-to-stand item,²⁷ a minimum chair height test, the timed 10-m walk and the 2-minute walk tests.²⁸ Walking speed, stride length and cadence were calculated from each subject's 10-m walk test score. The Nine-Hole Peg Test, a measure of motor control in reaching and placing object,²⁸ was included to test for the effects of motivation and test-familiarity factors.

Training programme

The training programme was portrayed to the children as similar to those conducted for sporting teams. A team atmosphere was created with each child given a team logo T-shirt. Each ses-

sion started with warm-up stretches of major muscle groups. Children then moved through a circuit of work stations at each of which they practised functional training and exercises designed to strengthen lower limb muscles, improve segmental control of the lower limbs, and improve balance. Two therapists supervised the class, giving individual training when needed, with assistance from one or two parents each session. The training programme included treadmill walking, standing balance exercises (crouching to pick up objects placed at the limit of stability), walking up and down ramps and stairs. Strength training was carried out as closed-chain exercise, with practice of forward and lateral step-ups and step-downs, sit-to-stands, leg press exercises, and heels raise and lower over a block. Exercises were performed intensively to an individualized maximum number of repetitions in order to promote motor learning and improve muscle strength and endurance.

Stations were equipped to allow each exercise to be increased or decreased in difficulty according to the child's level of disability or as the child's exercise performance improved. In weight-bearing exercises, resistance was provided solely by body weight. Each child progressed by increasing the number of repetitions, and by increasing exercise difficulty, for example, by decreasing seat height at the sit-to-stand station, or by increasing speed of movement.

Data analysis

To examine the effects of training on isometric muscle strength, a four-way ANOVA was carried out, with test session, muscle group, side of body and trial number as repeated measures factors. Thereafter, specific contrasts were written between baseline and pre-test group data, and post-test and follow-up group data, within one-way repeated measures ANOVAs. Baseline and pre-test means were compared for all 21 tests using repeated measures ANOVA. Since only one test showed a statistically significant improvement, performance was considered overall to be stable, and, to give the best estimate of each subject's pre-training status, baseline and pre-test scores on each variable were pooled into a variable called pre-training. For the data from the ordinal Motor Assessment Scale, the non-

parametric Friedman test was used. An adjusted overall isometric strength score for pre-training, post-test and follow-up phases was calculated by summing the strength scores from all muscle groups for each subject, then dividing this score by the subject's weight. Pearson's product-moment correlation coefficients were calculated between this overall isometric strength score and functional tests, and between the Lateral Step-up Test and other functional tests. Spearman's rank-order correlation was used when calculating coefficients involving the MAS. Significance was set at $p < 0.05$ for all statistical tests.

Subject 8 was not able to attend the baseline session so all trial attempts for this subject were recorded as the average of his trials at the pre-test session. Due to difficulty obtaining isometric strength measures from subject 7 at baseline session, these data were excluded from all ANOVA tests involving left and right hip flexors and extensor baseline data.

Results

Training effect

Isometric strength and functional test scores both demonstrated the same pattern: stability over the pre-training period, significant improvements following training and maintenance of gains at follow-up.

Isometric muscle strength tests

A significant increase in isometric strength was found overall between pre-test and post-test ($p < 0.001$) with no significant change thereafter, from post-test to follow-up, in any muscle group. Post hoc analysis of the significant muscle-by-test session interaction was carried out with a series of univariate repeated measures ANOVAs conducted between pre-training and post-test, and between post-test and follow-up. Increases in isometric strength were found to be significant in 7 of the 12 muscle groups tested (Table 1).

Functional strength tests and functional measures

Scores for the left and right Lateral Step-up Test, Motor Assessment Scale, minimum chair height test, time taken to walk 10 m, and stride

length all improved significantly between pre-training and post-test, and all were maintained at follow-up (Table 2, Figures 1–3). These results demonstrate that immediately following training the children's performance on the Lateral Step-up Test and their ability to stand up from a chair had improved, and that they were walking more quickly over 10 m, achieved predominantly through taking larger steps. These gains were maintained eight weeks following cessation of training. Time taken to perform the Nine-Hole Peg Test did not change between pre-training and post-test, or from post-test to follow-up (see Table 2), suggesting that general motivational or test familiarity factors were not the cause of the improvements observed in walking, sit-to-stand and strength tests after the training programme.

Correlations between measures

Correlational analysis was performed to assess the strength of the relationship between combined isometric muscle strength score, functional muscle performance (Lateral Step-up Test) and functional performance (sit-to-stand and walking tests). No correlation between isometric strength score and any functional test reached significance. However, the mean for the nine r -values decreased from a moderate value of 0.50 (95% confidence interval 0.41–0.59) at pre-training to weak values of 0.19 (0.11–0.28) at post-training, and 0.12 (0.03–0.21) at follow-up. In contrast, moderate to high correlations were found between the Lateral Step-up Tests and tests of walking and sit-to-stand throughout the three phases of the study (left leg: mean $r = 0.79$, SD 0.11; right leg: mean $r = 0.82$, SD 0.10).

Discussion

This study supports previous findings that have shown a strong relationship between strength and function in diverse groups of children with cerebral palsy.^{3,11–13} The major findings were that a short task-oriented programme of strengthening exercises and motor training, carried out as group circuit training, resulted in increased isometric muscle force and improved performance of walking and sit-to-stand. These gains were maintained eight weeks following cessation of training. The

Table 1 Results of isometric strength tests

Muscle group	Baseline		Pre-test		Pre-training (A)		Post-test (B)		Follow-up (C)		A-B effect		B-C effect	
	M	SD	M	SD	M	SD	M	SD	M	SD	$F_{1,7}$	p	$F_{1,7}$	p
L Hip extensors ^a (N)	52.5	13.8	61.7	16.4	57.1	12.1	93.1	37.9	88.2	34.9	10.4	0.018*	3.43	0.113
R Hip extensors ^a (N)	44.1	19.2	58.2	13.9	51.2	9.4	89.2	35.6	90.2	29.2	10.56	0.017*	0.01	0.936
L Hip flexors ^a (N)	27.0	9.0	24.9	5.9	25.9	5.9	39.2	11.7	45.3	14.5	15.71	0.007*	2.10	0.198
R Hip flexors ^a (N)	25.2	7.1	27.2	8.2	26.2	6.7	42.8	14.8	45.4	13.6	17.91	0.005*	0.48	0.513
L Knee extensors (N)	39.9	14.4	39.5	11.2	39.7	11.6	52.2	17.5	58.9	21.0	10.06	0.016*	3.11	0.121
R Knee extensors (N)	38.5	13.6	41.8	9.2	40.1	10.8	55.4	17.3	60.9	22.9	23.96	0.002*	1.74	0.229
L Knee flexors (N)	27.7	12.3	24.6	7.5	26.2	9.6	35.6	14.4	41.9	17.5	3.48	0.104	0.99	0.354
R Knee flexors (N)	27.8	10.8	22.6	8.9	25.2	9.5	34.5	13.7	42.1	15.7	5.30	0.055	2.35	0.169
L Plantarflexors (N)	45.7	22.9	45.4	20.4	45.6	18.8	57.1	21.9	61.5	24.2	6.24	0.041	0.26	0.626
R Plantarflexors (N)	43.0	30.5	43.3	23.7	43.1	24.1	57.3	22.6	56.0	17.3	2.41	0.165	0.02	0.892
L Dorsiflexors (N)	15.3	7.0	17.9	11.5	16.6	8.0	25.3	13.6	19.5	9.0	4.88	0.063	3.89	0.089
R Dorsiflexors (N)	12.0	6.1	14.0	10.2	13.0	7.9	20.7	11.0	22.2	12.1	13.19	0.008*	0.85	0.389

The table reports the means and standard deviations at baseline, pre-test, post-test and follow-up, with F scores and p -values of pre-training to post-test (A-B effect) and post-test to follow-up (B-C effect) comparisons.

* $p < 0.025$.

^a Hip muscle group data excludes one subject, hence F scores for all hip muscle tests have 1,6 degrees of freedom.

Table 2 Results of functional tests

Muscle group	Baseline		Pre-test		Pre-training (A)		Post-test (B)		Follow-up (C)		A-B effect		B-C effect	
	M	SD	M	SD	M	SD	M	SD	M	SD	$F_{1,7}$	p	$F_{1,7}$	p
L LSUT (repetitions)	3.3	3.4	3.4	3.5	3.3	3.3	7.9	3.8	6.8	3.8	42.83	0.001*	4.77	0.065
R LSUT (repetitions)	2.6	3.2	3.4	3.8	3.0	3.5	7.8	3.8	7.0	3.5	48.60	0.001*	2.74	0.142
MAS – STS Score ^a	1.5	2.0	1.5	1.5	1.5	1.8	2.0	4.0	2.5	3.5	6.00	0.014*	0.00	1.000
Min. chair height (cm)	26.8	15.1	27.0	15.6	26.9	15.3	16.6	11.5	16.6	13.5	24.99	0.002*	0.76	0.413
Walking speed (m/s)	0.71	0.35	0.69	0.33	0.70	0.35	0.88	0.36	0.86	0.48	4.21	0.079	0.03	0.874
Stride length (m)	0.67	0.20	0.67	0.17	0.67	0.19	0.82	0.18	0.79	0.24	13.66	0.008*	0.24	0.637
Cadence (steps/min)	120.1	38.7	116.0	40.6	118.1	39.1	123.8	31.6	121.5	43.5	0.33	0.584	0.06	0.812
10-m walk test (s)	20.3	13.8	21.3	14.8	20.8	14.3	14.0	7.7	18.0	14.3	5.68	0.049*	1.35	0.283
2-min walk test (m)	75.7	33.7	74.2	32.1	74.9	32.4	98.5	46.2	100.5	48.7	3.40	0.108	0.11	0.748
Nine-Hole Peg Test (s)	50.0	20.7	53.3	19.7	51.6	19.9	43.8	9.9	45.4	8.3	3.10	0.122	0.26	0.626

The table reports the means and standard deviations at baseline, pre-test, post-test and follow-up, with F scores and p -values of pre-training to post-test (A-B effect) and post-test to follow-up (B-C effect) comparisons.

* $p < 0.05$.

^aChi-square score given for MAS.

LSUT, Lateral Step-up Test.

study has limitations in the sample size of the single trained group, and in there being only one follow-up after the three previous assessment sessions. Nevertheless, the findings are in agree-

ment with other studies which have shown that strength training in cerebral palsy is associated with improvements in motor function.^{3,11-13}

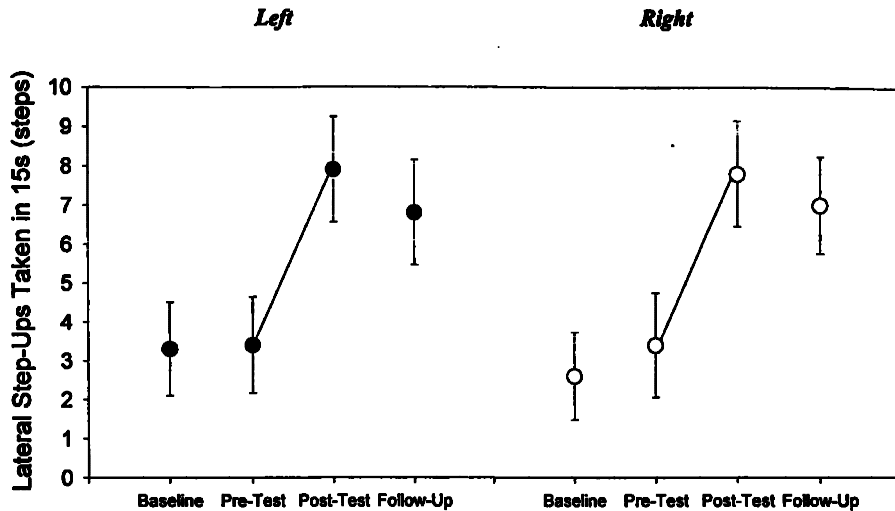


Figure 1 Results of the left and right Lateral Step-up Tests. The figure indicates the means and standard errors at baseline, pre-test, post-test and follow-up.

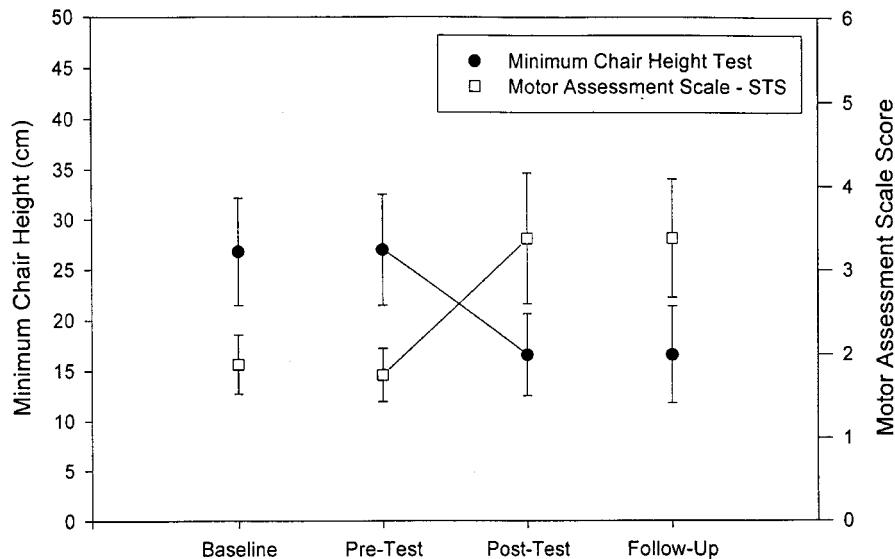


Figure 2 Results of the sit-to-stand tests. The figure indicates the means and standard errors for the Motor Assessment Scale and minimum chair height test at baseline, pre-test, post-test and follow-up.

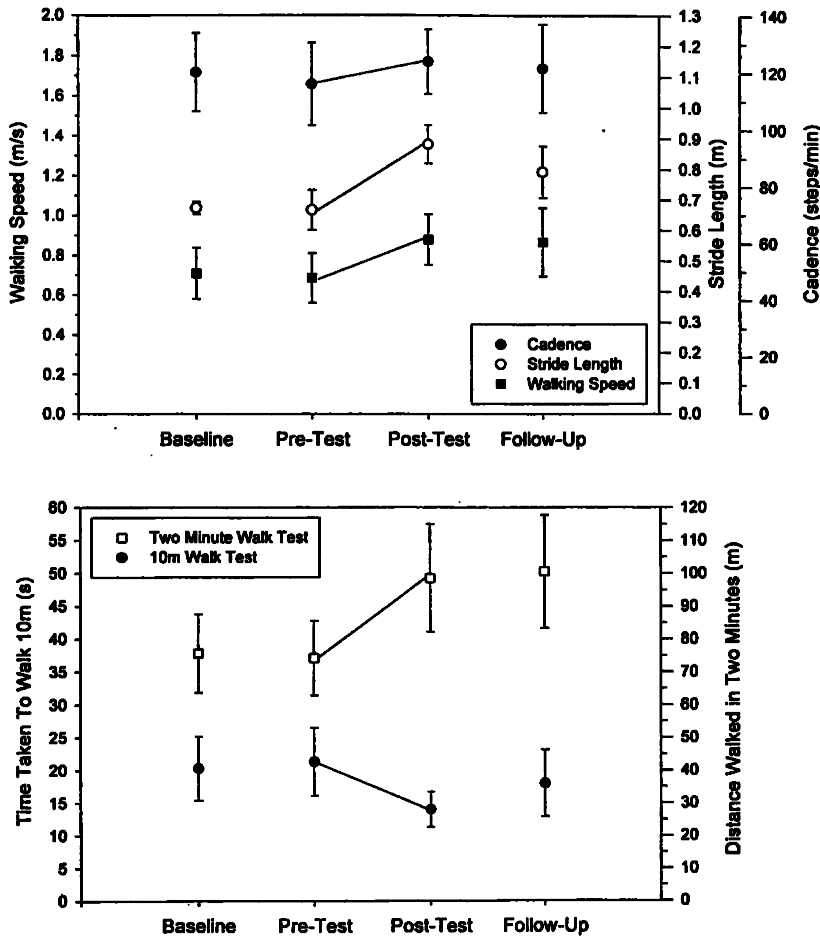


Figure 3 Results of walking tests. The figure indicates the means and standard errors for walking speed, stride length and cadence (top), and the 10-m walk test and the 2-minute walk test (lower) at baseline, pre-test, post-test and follow-up.

Previous studies have examined the effect of non-weight-bearing (open-chain) exercises, with resistance provided by free weights or an isokinetic dynamometer.^{3,11-13,16} The present study examined repetitive practice of weight-bearing (closed-kinetic-chain) exercises with similar characteristics to those found normally in many functional activities that involve the lower limbs in support, balance and propulsion.^{9,19,29} Resistance was provided by body weight. These exercises take into account the specificity of training principle, ensuring that force and power generated by muscles is directly related to the function being

trained.¹⁹ Such exercises have the potential to train aspects of motor performance such as coordination, balance, strength, endurance and physical conditioning.²⁹ Performed repetitively in a task-relevant environment, they would be expected to refine the efficient motor patterns required for optimal functional performance.^{30,31}

It is not surprising that the children improved on the measures of functional lower limb strength, the Lateral Step-up and minimum seat height tests, since step-ups and sit-to-stand were practised. It is of interest, however, that there was also an increase in the maximum isometric

Clinical messages

- Task-oriented weight-bearing (closed-chain) strength training for children with cerebral palsy can be effective in improving functional performance.
- Group training in a circuit class is effective, feasible and enjoyable for children.
- Arguments against strength training after upper motor neuron lesion are not supported by the evidence of this and other studies of adults and children.

muscle force that could be produced, since at no point were isometric exercises practised. Not all the muscles tested showed a significant increase in isometric strength. Of those that did, hip and knee extensors were specifically involved in all of the exercises, and hip flexors may have been strengthened by the periods of treadmill walking which facilitates pull-off by hip flexors at the start of swing. The failure of ankle dorsiflexors and plantarflexors to demonstrate a significant change may have been due to the presence of calf muscle contracture in several of the children.

The nature of the relationship between strength and function is of considerable relevance to clinical practice. A previous study has reported moderate to high correlations between isometric muscle strength and walking speed in children with cerebral palsy.³ In contrast, the correlations found in the present study between isometric strength and functional performance were not significant. Correlations between the Lateral Step-up Test and functional performance were, however, significant. Buchner *et al.*,³² in a study of older adults, suggested that a curvilinear relationship exists between lower limb function and strength. That is, below a certain threshold, strength has a direct linear relationship with functional ability. Above that threshold, further increases in strength may not be associated with corresponding increases in function; for example, no relationship was found between strength and walking speed in able-bodied younger adults.³² Buchner's work implies that once a minimum and task-dependent level of strength is attained, other factors such as task-oriented skill training become more important for improving functional

performance. In the present study, a decoupling consistent with this hypothesis was observed in the decline of strength of correlation between measured isometric strength and functional tests from pre-training through post-test to follow-up. The exercises in this study were designed to increase strength to the level required by the task rather than to maximize muscle force production. The fact that open-chain exercises in previous studies also resulted in improved functional performance may have reflected initial strength levels in the tested children.

The findings support the inclusion of strengthening exercises in paediatric practice and the use of the Lateral Step-up Test as a functional measure of improved performance of lower limb muscles.²⁵ The study also demonstrated the feasibility of group circuit training in children with severe motor disability. Organizing children into groups can provide a time-efficient, economical and effective form of therapy delivery.

The introduction of group dynamics into therapy may have increased motivation and exercise performance through aspects such as behaviour modelling.³³ The team approach and training themes advocated during this programme not only fostered healthy competition between the children, it encouraged the children to show support towards each other, and made therapy fun rather than a chore. The fact that most of the exercises comprised actions used every day and for which skill (effectiveness in goal attainment) is obviously needed may have added motivation. Giving children some control over practice conditions, and empowering them to view the therapist as coach, may also have encouraged their problem-solving abilities. The children completed all sessions and at the conclusion of each class had to be prompted to leave. The satisfaction with the programme demonstrated by the parents and the obvious enjoyment of the children together with the functional benefits demonstrated suggest that this model of training is a feasible and beneficial type of training for children with cerebral palsy.

Acknowledgements

The authors would like to acknowledge the Spastic Centre of New South Wales, especially Ms Julia Hanley, physiotherapist, for her contribution during data collection.

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