

A Novel Balance Training Program for Children With Developmental Coordination Disorder

A Randomized Controlled Trial

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Abstract: This study aimed to compare the effectiveness of a specific functional movement–power training (FMPT) program, a functional movement training (FMT) program and no training in the improvement of balance strategies, and neuromuscular performance in children with developmental coordination disorder (DCD).

It was a randomized, single-blinded, parallel group controlled trial.

Methods: 161 children with DCD (age: 6–10 years) were randomly assigned to the FMPT, FMT, or control groups. The 2 intervention groups received FMPT or FMT twice a week for 3 months. Measurements were taken before, after, and 3 months after the end of the intervention period. The primary outcomes were the composite score and strategy scores on the sensory organization test as measured by a computerized dynamic posturography machine. Secondary outcomes included the knee muscle peak force and the time taken to reach the peak force.

The balance strategies adopted in sensory challenging environments of the FMPT participants showed greater improvement from baseline to posttest than those of the FMT participants (7.10 points; 95% confidence interval, 1.51–12.69; $P=0.008$) and the control participants (7.59 points; 95% confidence interval, 1.81–13.38; $P=0.005$). The FMPT participants also exhibited greater improvement from baseline to the posttest in the knee extensor peak force and time to peak force in the knee flexors.

The FMPT program was more effective than the conventional FMT program in the enhancement of balance strategies and neuromuscular performance in children with DCD.

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Abbreviations: AP = anterior–posterior, CI = confidence interval, CNS = central nervous system, DCD = developmental coordination disorder, EMG = electromyographic, ES = equilibrium score, FMPT = functional movement–power training, FMT = functional movement training, SOT = sensory organization test, SS = strategy score, TKD = taekwondo.

INTRODUCTION

Developmental coordination disorder (DCD) is a common motor disorder with a prevalence of approximately 6% in typical children of primary school age. Children in whom DCD is diagnosed are characterized by marked impairment in various motor functions,¹ among which poor balance ability is a major concern because it predisposes children to falls, affects their motor skill development² and participation in activities.^{3–5} Evidence-based treatment strategies to improve balance performance must, therefore, be developed.

It is known that balance responses can be incorporated into hip and ankle strategies that maintain the body's anterior–posterior (AP) stability in a fixed stance.^{6,7} The hip strategy involves hip flexion and extension movements with opposing ankle joint dorsiflexion and plantar flexion. It is a relatively poor balance strategy because the center of gravity displacement is large and thus induces postural instability. A better balance strategy, the ankle strategy, involves maintaining standing balance while rotating the body as a rigid mass about the ankle joints.^{7,8} Recently, our research team discovered that children with DCD tend to use the hip strategy excessively when they are forced to rely on vestibular input to maintain standing balance,⁹ and slowed hamstring muscle force production, a neuromuscular deficit, could be one of the causes.¹⁰ However, the present treatment regimens for children with DCD primarily focus on the induction of neuroplastic changes in the central nervous system (CNS) to enhance functional balance performance by means of functional movement training (FMT) or a task-oriented approach.^{11–13} Less emphasis has been placed on the treatment of neuromuscular impairments, such as slowed hamstring muscle force production, that could also affect balance outcomes.¹¹ We postulated that interventions for children with DCD should address both the CNS and peripheral neuromuscular deficits to maximize their effectiveness in the improvement of postural control and thus the minimization of health care costs.

Power or strength training has been found to be effective in increasing the speed of muscle force production and balance in young people via various neuromuscular mechanisms.^{14,15} One recent case report has suggested that strength training may improve gross motor function in a child with DCD.¹⁶ Muscle

power training might therefore be an ideal adjunct therapy to FMT for the improvement of the overall balance performance in children with DCD. However, no experimental study has yet investigated this potentially beneficial treatment regimen. This study was performed to compare the effectiveness of power training with FMT, FMT alone, and no intervention in the improvement of balance strategies and performance in children with DCD. We hypothesized that power training with FMT would be more effective in improving neuromuscular and balance performance and balance strategies than FMT alone or no training.

METHODS

Study Design

This was a single-blind, stratified, randomized controlled clinical trial and was registered with ClinicalTrials.gov (NCT02393404). Ethical approval was obtained from the Human Research Ethics Committee of the University of Hong Kong. The study was explained to each participant and parent, and written informed consent was obtained.

Participants

Children with DCD were recruited from local child assessment centers, hospitals, schools, nongovernment organizations, and parent groups by means of poster and website advertising. The inclusion criteria were a diagnosis of DCD based on the Diagnostic and Statistical Manual of Mental Disorders IV;¹ a gross motor composite score of 42 or less on the Bruininks-Oseretsky Test of Motor Proficiency;¹⁷ aged between 6 and 10 years; and no intellectual impairment. The exclusion criteria were a diagnosis of an emotional, neurological, or other movement disorder (comorbid attention deficit hyperactivity disorder, attention deficit disorder, dyslexia, and suspected autism spectrum disorder were allowed); significant congenital, musculoskeletal, or cardiopulmonary disorders that might affect motor performance; active treatment; disruptive behaviour; or an inability to follow instructions.

Screening and Randomization

Two physiotherapists screened the volunteers by telephone, and those who seemed to meet the criteria stated above underwent an in-person evaluation and baseline assessment. The eligible participants were stratified by sex and randomly assigned to either the functional movement–power training (FMPT) group, the FMT group, or the control group in a ratio of 1:1:1. The randomization procedure was carried out by an independent person and used random number table to generate allocation sequence and numbered, sealed, and opaque envelopes to ensure concealed allocation.

Interventions

The FMT group received task-specific training concurrent with electromyographic (EMG) biofeedback to remediate motor learning difficulties¹² and enhance neuroplasticity and balance performance.^{18,19} The FMT training protocol, which was modified from the balance assessment items in the Movement Assessment Battery for Children,²⁰ is presented in Table 1. In addition, a 2-leg balance exercise (item 1) was added, during which the participant stood on a platform and EMG biofeedback was applied to the participant's dominant leg (i.e., the leg used to kick a ball)²¹ with the NeuroTrac MyoPlus 4 machine (Verity

Medical Ltd., Braishfield, UK). The activity of the rectus femoris and gluteus maximus muscles were monitored by visual feedback signals (vertical bargraphs)²² because these muscles are essential for the control of hip sway and also affect ankle movements.¹⁰ The participants were instructed to contract the agonistic hip muscle as fast as possible (increasing height of the corresponding EMG bargraph), when their balance was being perturbed in the AP direction and then to relax the muscle (decreasing height of the corresponding EMG bargraph) to avoid overbalancing. All participants practiced these balance strategies repeatedly for 10 minutes before they moved on to the other FMT exercises. Maximum voluntary isometric contraction of each muscle was documented using the same EMG machine prior to training. Participants were instructed not to contract their muscles strongly/greater than 70% maximum voluntary isometric contraction (denoted by a beep sound) during the intervention to avoid muscle fatigue. In addition, a short break was allowed if participants complained of muscle fatigue during training.

The participants in the FMPT group also received power/resistance training after the FMT. The power training exercises were intended to improve postural muscle strength and contraction speed in the legs. The training protocol, presented in Table 1, was derived from 2 resistance training programmes that are effective in increasing muscle contraction speed in young people.^{14,15} During the power training session, the participants contracted the gluteus maximus (squatting), iliopsoas (hip flexion), quadriceps (knee extension and squatting), hamstrings (hamstring curls), tibialis anterior (ankle dorsiflexion), and gastrocnemius and soleus (seated calf raises and squatting) muscles as quickly as possible against a load (70% of 1 repetition maximum). These leg muscles were selected because their strength and rate of strength development are important for control of the AP body sway while standing.²³ The 1 repetition maximum, which is defined as the maximum load that can be lifted 1 time,²⁴ was tested during the 1st session and every month throughout the intervention period. The training load (i.e., cuff weights) relative to the 1 repetition maximum was adjusted accordingly as a kind of progression.¹⁵ Each training session was supervised by a physiotherapist and conducted by a trained assistant. The children in the FMPT and FMT groups attended 2 training sessions per week (1.5 hours per session) at the University of Hong Kong Physical Activity Laboratory for 12 weeks.²⁵ The control group received no training but continued their usual daily activities.

Primary Outcomes

Standing balance and balance strategies were assessed using the sensory organization test (SOT), which is a valid and reliable test in children.^{26,27} Each participant was instructed to stand barefoot on the force platform of a computerized dynamic posturography machine (Smart Equitest, NeuroCom International Inc., OR). The foot placement was standardized according to the participant's height. Each participant was then exposed to 6 sensory conditions of 3 trials each (18 trials in total). The sensory inputs (i.e., somatosensory, visual, and vestibular) available for each SOT condition have been fully described in our previous papers.^{3,9,28} The machine captured the trajectory of the participant's center of pressure during the 18 trials and generated an equilibrium score (ES) for each trial. The composite ES score (ranging from 0 to 100) from all 18 trials was used for analysis. It reflects the participant's general balance ability during standing.²⁹

TABLE 1. Functional Movement–Power Training and Functional Movement Training Protocols*

Type of Exercise and Progression	Frequency	Intensity	Duration	Aims of Exercise
Functional movement training				
1. Two-leg balance on a stability trainer in conjunction with electromyographic biofeedback to control anterior–posterior body sway.	Twice per week	Not beyond muscle fatigue (<70% MVIC)	10 minutes	To train bipedal static balance and proprioception; electromyographic biofeedback enhances motor learning and central nervous system plasticity.
2. One-leg balance on the ground. Progress to one-leg balance on a balance board with jumping stand base (alternate foot).		Not beyond muscle fatigue (subjective feeling)	5 minutes	To train unilateral static balance and proprioception.
3. Walk along a straight line (4.5 m) with heels raised. Progress to heel-to-toe walk along a straight line (4.5 m).		20 repetitions	5 minutes	To train dynamic balance and coordination; to facilitate dynamic coordinated muscle contractions in the limbs and trunk.
4. Double-leg hop or jump forward. Progress to single-leg hop forward (alternate foot).		50 hops (each foot)	5 minutes	To train dynamic balance and coordination; to strengthen the hip and knee extensors and calf muscles.
5. Walk and balance a ball on a peg board simultaneously.		Walk 50 m	5 minutes	To train dynamic balance and coordination.
Power training				
1. Squatting exercise	Twice per week	4 sets, 10 repetitions, 70% 1 repetition maximum for each leg (Progression: repetition maximum is tested every month, and the training load is adjusted accordingly)	5 minutes each (with 2-minute rest period between sets)	To improve lower-limb muscle strength, power, and contraction speed.
2. Isolated hip flexion in supported standing				
3. Isolated knee extension in sitting				
4. Hamstring curls while lying prone				
5. Seated ankle dorsiflexion				
6. Seated calf raises				

MVIC = maximum voluntary isometric contraction.

*The functional movement–power training group followed the entire protocol. The functional movement training group received only the 5 functional movement training exercises. The control group received no intervention.

In addition to the ES score, the machine also detected the shear force in the AP direction and generated a strategy score (SS) that represents the amount of ankle and hip movement used in maintaining balance under the 6 sensory conditions. The SS was calculated according to the formula:

$$SS = [1 - (SH_{\max} - SH_{\min}) / 25 \text{ lbs}] \times 100$$

where SH_{\max} represents the greatest horizontal AP shear force detected by the force platform and SH_{\min} is the smallest. Their difference was normalized to 25 lbs (111.25 N) of shear force, which is the average difference between the highest and lowest AP shear forces generated by a group of normal participants who used hip sway only to balance on a narrow beam.²⁹ An SS of 100 indicates that the participant predominantly used the ankle to maintain standing balance, whereas an SS of 0

indicates that the participant mainly used the hip strategy. An independent SS (ranging from 0 to 100) was obtained for each test trial, and the average SS of all 18 trials was derived.²⁹ The average SS for each sensory condition and the overall average SS were used for analysis.

Secondary Outcomes

The maximum isometric muscle strength (peak force) of the participants' dominant knee flexors and extensors was measured using the Lafayette Manual Muscle Test System (Model 01165, Lafayette Instrument Company, Lafayette, LA) with standardized manual muscle testing procedures³⁰ and dynamometer placements.³¹ Good to perfect reliability (intraclass correlation coefficient: 0.81–0.98) has been

reported.³² Each participant completed 2 trials of manual muscle testing during which the peak force was generated for 2 seconds for each muscle group. The participants were instructed to voluntarily contract their muscles as hard and as quickly as possible. The average peak force of the 2 trials was used for analysis. The mean time to peak force, defined as the elapsed time from the start of the test until the maximum force is reached,³¹ was also documented for data analysis.

Test Procedures

Data collection was performed at the Balance Laboratory of the Hong Kong Polytechnic University by a physiotherapist and a trained assistant who were blinded to the group allocation. All participants were assessed before the start of the interventions (baseline), immediately after the interventions (posttest), and 3 months after the end of the interventions (follow-up test).

Statistical Analyses

On the basis of our pilot trial, we estimated that a sample of 45 participants per group would provide at least 80% power to detect a between-groups difference in a mean change from baseline to 3 months of 0.335 points in the primary outcomes, assuming a 25% attrition rate, at a 2-tailed alpha level of 5%. These predicted mean point differences equate to a medium to large effect size of 0.67.

All of the analyses were conducted on an intention-to-treat basis (last-observation-carried-forward method). The between-groups differences in demographic variables were assessed with 1-way analysis of variance for continuous data and with a Chi-square test for categorical data (i.e., sex, coexisting conditions, and routine medication). Baseline primary and secondary outcome variables were also assessed with 1-way analysis of variance to detect any significant between-groups differences before the interventions. Any changes in the primary and secondary outcomes following the intervention were quantified by subtracting the baseline scores from the postintervention scores. The differences from the baseline in each outcome measure were analyzed with mixed-model repeated-measures analysis of variance (between-subjects factor: group; and within-subject factor: time) followed by post-hoc tests. All *P* values were corrected using Bonferroni method to maintain the overall significance level at 5% (2-tailed). The results are presented as means with SDs or 95% confidence intervals (CIs). All of the statistical analyses were performed with SPSS 20.0 (IBM).

RESULTS

Study Population

From January to May 2014, 178 children were screened for eligibility; 161 qualified and underwent randomization: 53 to the FMPT group, 55 to the FMT group, and 53 to the no-training control group (Figure 1). The reasons for exclusion from the study were a formal diagnosis of autism spectrum disorder (*n* = 6), rehabilitation therapy outside the study (*n* = 5), and an inability to follow instructions (*n* = 4). Two participants declined to participate in the study without giving a reason.

No statistically significant differences in any of the participant's baseline characteristics were found among the 3 groups (Table 2). A total of 130 children completed the interventions and the 3-month evaluation. Among which, 122 children (76%) completed the 6-month evaluation. No statistically significant

differences were seen in the baseline demographic data between the participants who successfully completed the study and those who did not. Moreover, the attendance rates of the FMPT and FMT interventions were 83% and 79%, respectively (Figure 1). The attendance rates demonstrated no significant difference between the 2 intervention groups (*P* = 0.221). No changes in the participants' medication used or physical activity level were noted overtime within the 3 groups.

Primary Outcomes

Tables 3, 4, and Figure 2 show the mean changes from baseline to 3 and 6 months in the 3 groups for all outcomes. At 3 months, only the FMPT group had a significant improvement in the SS in condition 6 (6.06 points; 95% CI −9.97 to −2.15; *P* = 0.003). The mean difference between the FMPT and FMT groups was 7.10 points (*P* = 0.008), whereas the difference between the FMPT and control groups was 7.59 points (*P* = 0.005). These between-groups differences in the SS in condition 6 gradually increased after the intervention period. At 6 months, the FMPT group had a significant improvement in the SS in condition 6 (8.21 points; 95% CI −12.27 to −4.15; *P* < 0.001). The between-groups differences were 8.43 points (*P* = 0.001) between the FMPT and FMT groups and 10.03 points (*P* < 0.001) between the FMPT and control groups. The overall SS and the SS for conditions 1 to 5 remained relatively stable in all 3 groups overtime.

Regarding balance performance, both the FMPT and FMT groups had greater improvement at 3 months than did the control group, as measured by the change in the composite ES. Specifically, from baseline to 3 months, the children in the FMPT and FMT groups had mean increases in the composite ES of 5.16 points (95% CI −7.81 to −2.53; *P* < 0.001) and 3.69 points (95% CI −6.13 to −1.25; *P* = 0.004), respectively. No significant change was observed in the control group. However, none of the between-groups differences were significant. The improvement in the composite ES in the FMT group was maintained at 6 months (mean change from baseline to 6 months, 5.44 points; 95% CI −8.36 to −2.54; *P* < 0.001) only, but the between-groups differences were not significant. A separate analysis was performed after removal of the dropouts (on-protocol analysis), and similar results were obtained (data not shown).

Secondary Outcomes

The changes from baseline to 3 months in the time to peak force of the knee flexors also favored the FMPT group (−0.32 seconds; 95% CI 0.06–0.58; *P* = 0.016) over the other 2 groups, and the difference between the FMPT and control groups was significant (−0.33 seconds; 95% CI, −0.65 to −0.003; *P* = 0.047). However, this improvement in the FMPT group was not maintained at 6 months. Instead, the change from baseline to 6 months in the time to peak force of the knee flexors was significant in the FMT group (−0.15 seconds; 95% CI 0.04–0.26; *P* = 0.009); however, no significant between-groups differences were found.

Improvement in the peak force of the knee extensors at 3 months was seen only in the FMPT group (0.63 kg; 95% CI −1.01 to −0.26; *P* = 0.001), but the mean between-groups differences were not significant. The improvement was not maintained at 6 months in the FMPT group (*P* = 0.105). No significant changes from baseline to 3 and 6 months were observed in the peak force of the knee flexors and the time to peak force of knee extensors in any of the groups (Figure 2).

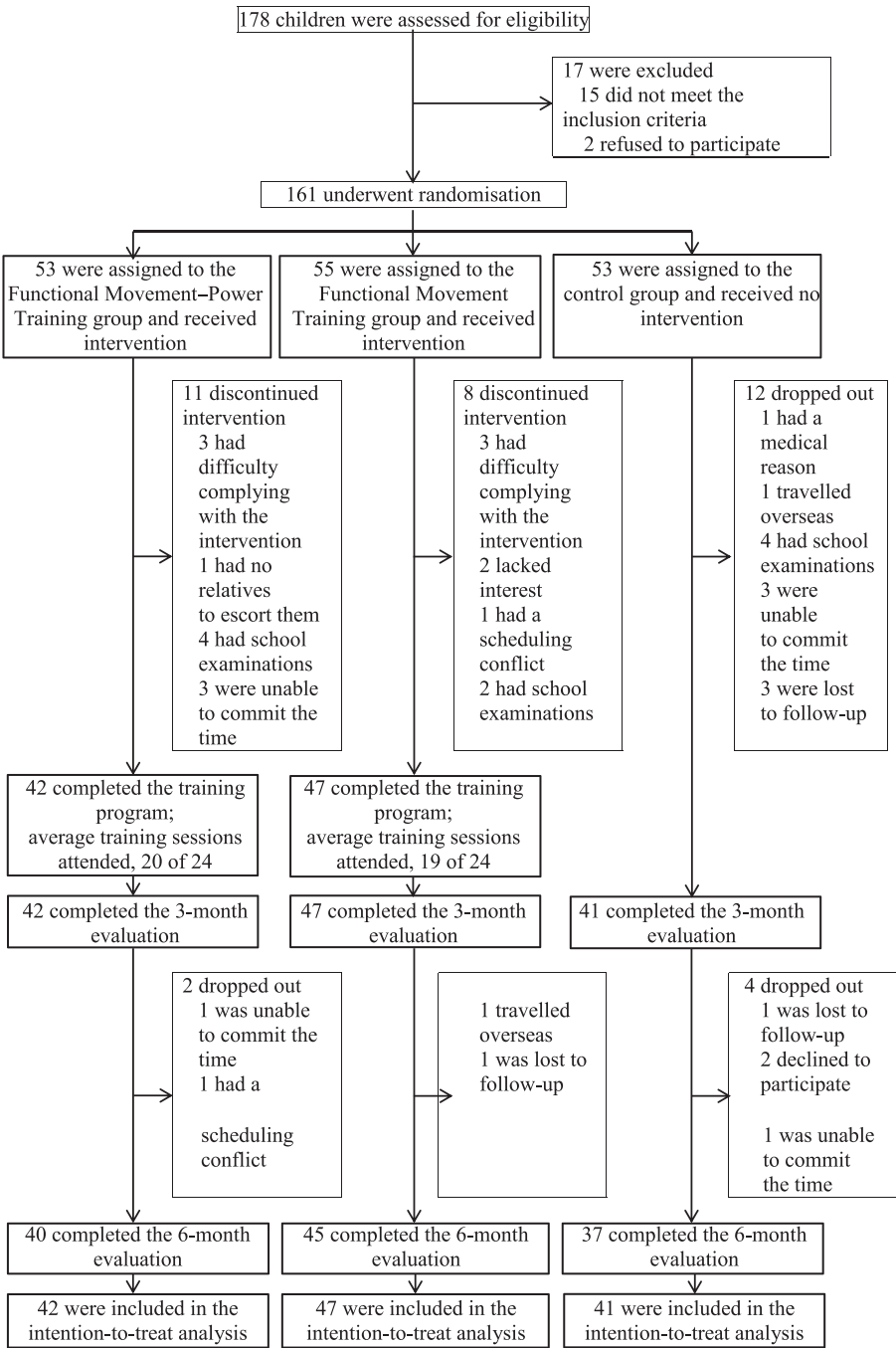


FIGURE 1. Participant flow chart.

Adverse Events

No adverse events were reported during the laboratory assessments. The training-related adverse events were mild: transient muscle soreness (2 subjects in both FMPT and FMT groups) and falls without injury (1 in the FMT group).

DISCUSSION

This study is the first to show that a 3-month program of twice-weekly FMPT was more effective than FMT alone or no

training in improving balance strategies (i.e., a decrease in reliance on the hip strategy and an increase in reliance on the ankle strategy) in a sensorially challenging environment (e.g., only vestibular input was available in SOT condition 6) in children with DCD. The improvements were maintained for 3 months after the cessation of training. This finding supports our hypothesis that the balance strategies of children with DCD can be improved most by treating both their CNS and neuromuscular deficits. Theoretically, FMT can induce neuroplastic changes in the CNS (e.g., modification of Purkinje cell synapses

TABLE 2. Baseline Characteristics of the Participants*

Characteristic	Functional Movement–Power Training (n = 42)	Functional Movement Training (n = 47)	Control (n = 41)	P
Age, year	7.8 (1.3)	7.9 (1.4)	7.5 (1.6)	0.343
Sex – no., %				
Male	28 (66.7%)	33 (70.2%)	28 (68.3%)	0.937
Female	14 (33.3%)	14 (29.8%)	13 (31.7%)	
Weight, kg	25.1 (7.4)	25.8 (8.1)	24.5 (8.3)	0.754
Height, cm	123.6 (9.5)	125.2 (11.0)	121.5 (11.2)	0.270
Body mass index, kg/m ^{2†}	16.1 (2.4)	16.1 (2.5)	16.2 (2.7)	0.975
Physical activity level – MET, hours/week [‡]	12.0 (8.4)	15.6 (13.4)	17.2 (13.9)	0.142
Movement Assessment Battery for Children total impairment score [§]	17.0 (4.9)	15.4 (6.5)	15.5 (4.2)	0.286
Coexisting conditions – no., %				0.987
Attention deficit hyperactivity disorder	9 (21.4%)	10 (21.3%)	10 (24.4%)	
Dyslexia	6 (14.3%)	5 (10.6%)	7 (17.1%)	
Suspected autism spectrum disorder	10 (23.8%)	12 (25.5%)	13 (31.7%)	
Routine medication for attention deficit hyperactivity disorder – no., % [§]				0.943
Ritalin	2 (4.8%)	1 (2.1%)	1 (2.4%)	
Concerta	1 (2.4%)	2 (4.3%)	1 (2.4%)	
Unknown	1 (2.4%)	1 (2.1%)	1 (2.4%)	

MET = metabolic equivalent, SD = standard deviation.

*All values are means (SD) unless noted otherwise.

[†]The body mass index is the body weight (kg) divided by the square of the height (m).

[‡]The physical activity level, in MET hours per week, was estimated on the basis of the exercise intensity (light, moderate, or hard effort), duration (hours per exercise session), frequency (number of exercise sessions per week), and the assigned MET value of the activity (i.e., the type of physical activity in which the participant had most actively engaged during a typical week within the past year) according to the Compendium of Energy Expenditures for Youth. Higher scores indicate higher levels of habitual physical activity.

[§]The Movement Assessment Battery for Children total impairment score reflects the participants' overall manual dexterity, ball skills and balance ability. A lower score represents better general motor proficiency.

^{||}Coexisting conditions and medication were self-reported. Participants could report more than one coexisting condition.

TABLE 3. Outcome Measures at Baseline, 3 and 6 months*

Outcome Variable	Functional Movement–Power Training (n = 42)	Functional Movement Training (n = 47)	Control (n = 41)
Primary outcomes			
SOT composite equilibrium score [†]			
Baseline [‡]	53.60 (7.71)	52.10 (9.47)	51.91 (13.72)
Change from baseline			
3 months	5.17 (8.47)	3.69 (8.31)	1.38 (8.59)
6 months	4.31 (8.55)	5.45 (9.92)	2.92 (8.81)
SOT overall strategy score [§]			
Baseline [‡]	87.01 (3.61)	86.82 (3.64)	86.81 (4.67)
Change from baseline			
3 months	1.30 (4.30)	0.24 (2.69)	−0.08 (2.93)
6 months	1.61 (4.44)	0.48 (2.94)	0.01 (3.05)
SOT condition 1 strategy score [§]			
Baseline [‡]	98.98 (2.25)	98.83 (2.55)	99.07 (0.88)
Change from baseline			
3 months	0.01 (1.67)	0.18 (1.92)	−0.01 (0.80)
6 months	−0.15 (2.55)	0.29 (1.89)	−0.01 (0.80)
SOT condition 2 strategy score [§]			

Outcome Variable	Functional Movement–Power Training (n = 42)	Functional Movement Training (n = 47)	Control (n = 41)
Baseline [‡]	99.02 (1.54)	98.86 (2.02)	98.53 (1.64)
Change from baseline			
3 months	–0.51 (2.11)	0.39 (2.10)	0.10 (1.77)
6 months	–0.40 (1.78)	0.50 (1.99)	0.21 (1.55)
SOT condition 3 strategy score [§]			
Baseline [‡]	97.29 (5.29)	97.25 (5.34)	97.54 (3.03)
Change from baseline			
3 months	–0.01 (3.87)	1.75 (5.35)	–0.56 (4.08)
6 months	–0.41 (4.33)	1.31 (5.28)	–0.05 (2.88)
SOT condition 4 strategy score [§]			
Baseline [‡]	83.25 (6.68)	83.78 (3.70)	82.46 (6.86)
Change from baseline			
3 months	–0.96 (6.25)	–0.88 (3.52)	–0.27 (1.26)
6 months	–0.54 (6.56)	–1.79 (4.87)	–0.27 (1.26)
SOT condition 5 strategy score [§]			
Baseline [‡]	73.72 (8.35)	72.53 (10.93)	73.47 (11.97)
Change from baseline			
3 months	3.20 (14.81)	1.01 (7.16)	1.80 (13.71)
6 months	2.94 (14.84)	2.80 (7.77)	1.98 (14.12)
SOT condition 6 strategy score [§]			
Baseline [‡]	69.76 (11.20)	69.67 (11.68)	69.81 (12.97)
Change from baseline			
3 months	6.06 (12.54)	–1.04 (11.53)	–1.53 (7.74)
6 months	8.21 (13.03)	–0.22 (11.14)	–1.82 (7.91)
Secondary outcomes			
Peak force of knee extensors, kg			
Baseline [‡]	7.21 (2.30)	7.45 (0.78)	7.47 (3.22)
Change from baseline			
3 months	0.64 (1.20)	0.61 (2.27)	–0.04 (1.63)
6 months	0.54 (2.10)	0.46 (2.05)	–0.18 (1.65)
Peak force of knee flexors, kg			
Baseline [‡]	5.97 (1.76)	5.81 (2.65)	5.92 (2.42)
Change from baseline			
3 months	0.55 (2.05)	0.18 (1.69)	0.08 (0.64)
6 months	–0.12 (1.60)	–0.02 (1.85)	–0.19 (0.99)
Time to peak force of knee extensors, second [¶]			
Baseline [‡]	2.22 (0.49)	2.22 (0.49)	2.22 (0.46)
Change from baseline			
3 months	–0.16 (0.47)	–0.01 (0.31)	–0.02 (0.27)
6 months	–0.10 (0.57)	0.01 (0.36)	–0.01 (0.33)
Time to peak force of knee flexors, second [¶]			
Baseline [‡]	2.24 (0.52)	2.21 (0.39)	2.05 (0.50)
Change from baseline			
3 months	–0.32 (0.83)	–0.11 (0.43)	0.01 (0.52)
6 months	–0.25 (0.71)	–0.15 (0.38)	–0.01 (0.65)

SD = standard deviation, SOT = sensory organization test.

* All values are means (SD) unless noted otherwise. Change scores were calculated as (3-month – baseline) and (6-month – baseline).

[†]The SOT is an objective assessment of static standing balance. The participants were exposed to 6 sensory conditions in sequence: condition 1 – accurate somatosensory, visual, and vestibular input; condition 2 – accurate somatosensory and vestibular input, with no visual input; condition 3 – accurate somatosensory and vestibular input, with inaccurate visual input; condition 4 – accurate visual and vestibular input, with inaccurate somatosensory input; condition 5 – accurate vestibular input only, with no visual input and inaccurate somatosensory input; and condition 6 – accurate vestibular input only, with inaccurate visual and somatosensory input. The computer-generated composite equilibrium score ranges from 0 to 100, with higher scores indicating better overall postural stability in all 6 conditions.

[‡]The baseline characteristics were comparable among the 3 groups ($P > 0.05$) according to the results of analysis of variance.

[§]The overall strategy score and condition-specific strategy score of the SOT also range from 0 to 100, with higher scores indicating the increased use of the ankle strategy and less use of the hip strategy to maintain standing balance.

^{||}The isometric peak forces of the knee extensors and flexors were measured with a hand-held dynamometer, with higher scores indicating greater peak isometric muscle strength.

[¶]The time to the peak force of the knee extensors and flexors were also quantified with a hand-held dynamometer, with lower scores indicating faster muscle force production.

TABLE 4. Between-Groups Differences in Mean Change From Baseline of All Outcome Measures*

Outcome Variable	Between-Groups Difference in Mean Change From Baseline								
	FMPT Vs FMT (95% CI)	<i>P</i> [†]	Effect Size	FMPT Vs Control (95% CI)	<i>P</i> [†]	Effect Size	FMT Vs Control (95% CI)	<i>P</i> [†]	Effect Size
Primary outcomes									
SOT composite equilibrium score									
3 months	1.47 (−2.88, 5.83)	1.000	0.18	3.78 (−0.72, 8.29)	0.131	0.44	2.31 (−2.07, 6.69)	0.611	0.27
6 months	−1.14 (−5.85, 3.57)	1.000	0.12	1.39 (−3.48, 6.26)	1.000	0.16	2.53 (−2.22, 7.27)	0.595	0.27
SOT overall strategy score									
3 months	1.06 (−0.67, 2.79)	0.417	0.30	1.38 (−0.41, 3.17)	0.193	0.38	0.31 (−1.43, 2.06)	1.000	0.11
6 months	1.13 (−0.69, 2.94)	0.404	0.30	1.60 (−0.28, 3.48)	0.122	0.42	0.47 (−1.35, 2.30)	1.000	0.16
SOT condition 1 strategy score									
3 months	−0.17 (−0.97, 0.64)	1.000	0.09	0.02 (−0.82, 0.85)	1.000	0.02	0.18 (−0.63, 1.00)	1.000	0.13
6 months	−0.44 (−1.42, 0.53)	0.818	0.20	−0.15 (−1.16, 0.86)	1.000	0.07	0.30 (−0.69, 1.28)	1.000	0.21
SOT condition 2 strategy score									
3 months	−0.90 (−1.93, 0.14)	0.111	0.43	−0.61 (−1.68, 0.46)	0.499	0.31	0.28 (−0.76, 1.32)	1.000	0.15
6 months	−0.90 (−1.82, 0.03)	0.059	0.48	−0.61 (−1.57, 0.34)	0.367	0.37	0.29 (−0.64, 1.22)	1.000	0.16
SOT condition 3 strategy score									
3 months	−1.76 (−4.09, 0.57)	0.207	0.38	0.55 (−1.86, 2.96)	1.000	0.14	2.31 (−0.03, 4.66)	0.055	0.49
6 months	−1.72 (−3.95, 0.51)	0.192	0.36	−0.36 (−2.67, 1.95)	1.000	0.10	1.36 (−0.89, 3.61)	0.432	0.32
SOT condition 4 strategy score									
3 months	−0.08 (−2.24, 2.08)	1.000	0.02	−0.68 (−2.92, 1.55)	1.000	0.15	−0.60 (−2.78, 1.57)	1.000	0.23
6 months	1.25 (−1.22, 3.72)	0.665	0.22	−0.27 (−2.82, 2.28)	1.000	0.06	−1.52 (−4.00, 0.97)	0.422	0.43
SOT condition 5 strategy score									
3 months	2.18 (−4.10, 8.47)	1.000	0.19	1.40 (−5.09, 7.89)	1.000	0.10	−0.78 (−7.11, 5.54)	1.000	0.07
6 months	0.14 (−6.29, 6.57)	1.000	0.01	0.96 (−5.69, 7.61)	1.000	0.07	0.82 (−5.65, 7.29)	1.000	0.07
SOT condition 6 strategy score									
3 months	7.10 (1.51, 12.69)	0.008	0.59	7.59 (1.81, 13.38)	0.005	0.73	0.50 (−5.13, 6.12)	1.000	0.05
6 months	8.43 (2.80, 14.06)	0.001	0.70	10.03 (4.20, 15.85)	<0.001	0.93	1.60 (−4.07, 7.26)	1.000	0.17
Secondary outcomes									
Peak force of knee extensors, kg									
3 months	0.02 (−0.90, 0.94)	1.000	0.02	0.68 (−0.27, 1.63)	0.256	0.48	0.66 (−0.27, 1.58)	0.262	0.33
6 months	0.08 (−0.92, 1.09)	1.000	0.04	0.72 (−0.32, 1.75)	0.291	0.38	0.63 (−0.38, 1.64)	0.393	0.34
Peak force of knee flexors, kg									
3 months	0.37 (−0.45, 1.19)	0.815	0.20	0.47 (−0.37, 1.32)	0.533	0.31	0.10 (−0.72, 0.92)	1.000	0.08
6 mo	−0.10 (−0.89, 0.70)	1.000	0.06	0.07 (−0.75, 0.89)	1.000	0.05	0.17 (−0.63, 0.97)	1.000	0.11
Time to peak force of knee extensors, second									
3 months	−0.15 (−0.34, 0.03)	0.142	0.38	−0.14 (−0.33, 0.05)	0.255	0.37	0.02 (−0.17, 0.20)	1.000	0.03
6 months	−0.11 (−0.34, 0.11)	0.657	0.23	−0.09 (−0.32, 0.14)	1.000	0.19	0.03 (−0.20, 0.25)	1.000	0.06
Time to peak force of knee flexors, second									
3 months	−0.22 (−0.53, 0.10)	0.294	0.32	−0.33 (−0.65, −0.003)	0.047	0.48	−0.11 (−0.43, 0.20)	1.000	0.25
6 months	−0.10 (−0.41, 0.20)	1.000	0.18	−0.24 (−0.55, 0.07)	0.200	0.35	−0.14 (−0.44, 0.17)	0.829	0.26

CI = confidence interval, FMPT = functional movement–power training, FMT = functional movement training, SOT = sensory organization test.

*Mean values with 95% CIs are reported for all between-group differences. Change scores were calculated as (3-month – baseline) and (6-month – baseline).

[†]*P* values were derived from analysis of variance and post hoc pairwise comparisons, with an overall significance level of 0.05.

in the cerebellum),^{11,12} and power training can increase the speed of muscle contraction (force production) via several neuromuscular mechanisms: earlier motor unit activation, enhanced maximal motor unit firing rate in the initial stages of activation,¹⁵ increased efferent neural drive to the agonist muscles,¹⁴ improved intermuscular and intramuscular coordination, and improved force control.³³ In fact, we found that the children with DCD required a shorter time to reach the peak force in the knee flexors and had greater peak force in the knee extensors after FMPT training. These findings may explain the decreased use of the hip strategy (hip sway) in the participants in the FMPT group because their hamstrings and rectus femoris could contract strongly and in

a timely fashion to control the hip flexion-extension movements when their balance was challenged.¹⁰

Although only the FMPT improved balance strategies, both the FMPT and FMT were effective in improving the overall standing balance performance in children with DCD. In addition, the improvement was maintained at 6 months in the FMT group, probably because FMT required the children to practice the balancing movements repeatedly with EMG biofeedback, which can effectively enhance CNS plasticity.^{11,25,34,35} In addition, the increased concomitant muscle force production speed of the knee flexors in the FMT group at 6 months may also have contributed to the improvement in balance performance. Further study is

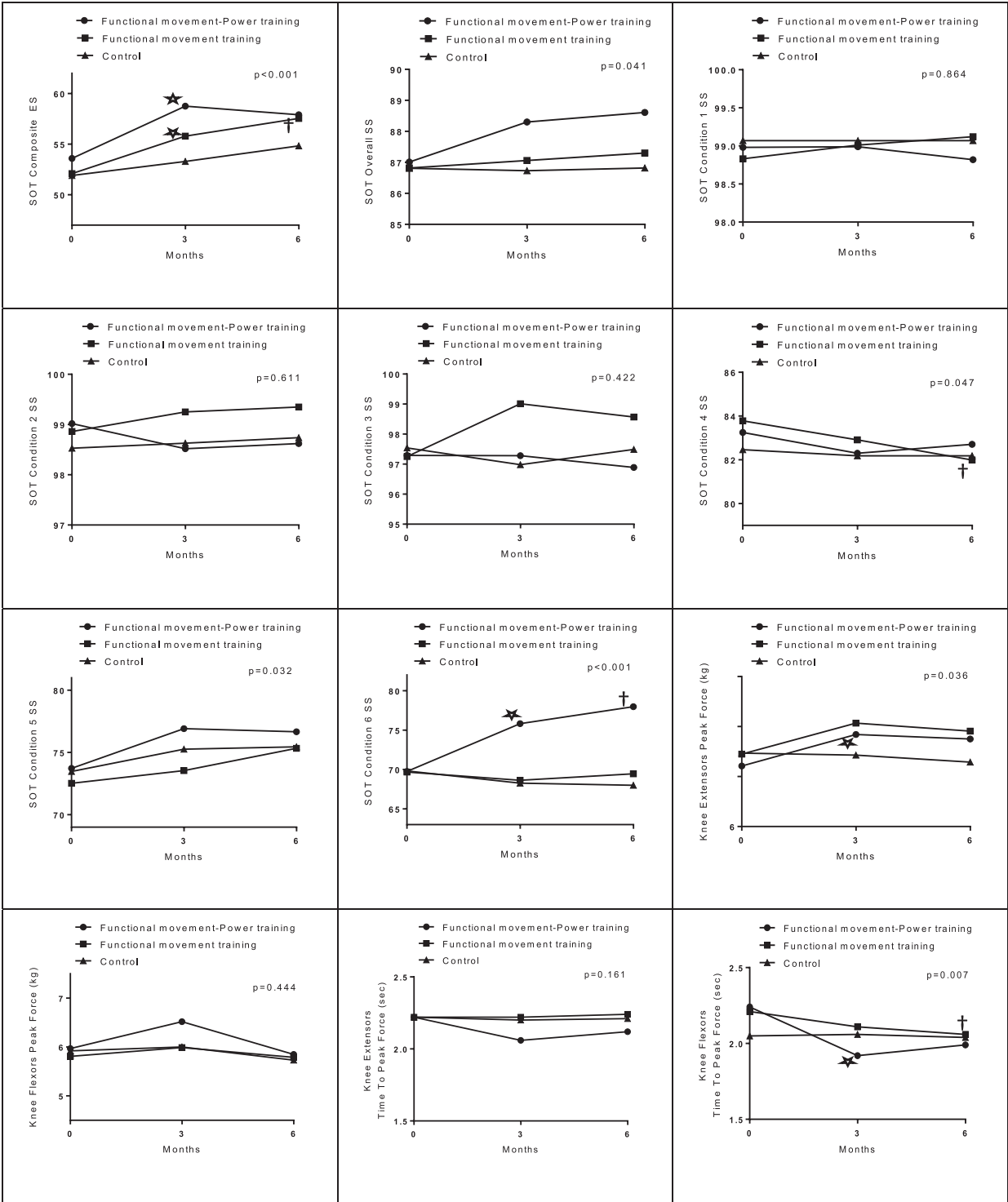


FIGURE 2. Mean changes in all outcomes at 3 and 6 months.

necessary to explore the relationships among balance performance, balance strategies, and muscle force production speed in children with DCD.

The present study demonstrated that integration of power training with FMT can improve the overall standing balance

performance, balance strategies, and knee muscle strength in children with DCD. Our previous studies showed that intensive martial art (taekwondo [TKD]) training can also improve standing balance performance and knee muscle strength in the DCD population.^{9,36} So, which intervention is better? We postulated that

FMPT may be a better choice than TKD given the fact that the power training component was specifically designed for strengthening lower extremity postural muscles, and children can practice FMPT at home easily without the use of martial art training equipment (TKD kick pad). In addition, we hypothesized that only FMPT can improve balance strategies of children with DCD, but not TKD training. It is because biomechanical analyses showed that TKD practitioners used a lot of hip strategy, rather than ankle strategy, to maintain postural stability during kicking.³⁷ Certainly, further experimental study is necessary to compare the efficacy of these 2 interventions for improving balance performance and balance strategies in children with DCD.

The major limitation of this study was that the participants were not blinded to the group assignment, given the nature of exercise training. The participants who were assigned to the intervention groups may have had expectations about the benefits of exercise, which may have introduced some biases in the results.³⁸ Another limitation was that the balance strategies were estimated from the horizontal AP shear forces detected by the force plate.²⁹ Further studies could assess hip, knee, and ankle movements directly using kinematic measures such as electrogoniometry. Moreover, EMG biofeedback was used during FMT but the signals were not captured. Further studies could record the EMG signals during both FMT and FMPT and treat EMG muscle activity as an outcome measure to indicate the neuromuscular performance before and after trainings. Finally, this was a laboratory-based study. It is not certain whether the improved balance performance in children with DCD can be carried over to daily activities.

CONCLUSIONS

FMPT led to better results than conventional FMT in the improvement of balance strategies in a sensorially challenging environment, and the neuromuscular performance of children with DCD. FMPT appears to be effective as a stand-alone intervention designed to improve balance strategies, postural stability, and leg muscle performance in children with DCD.

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