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A school-based physical activity intervention for children with developmental coordination disorder: A randomized controlled trial

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ABSTRACT

Background: Children with developmental coordination disorder (DCD) have lower physical activity (PA) than children with typical development (TD). PA and fundamental movement skills (FMS) are positively associated so interventions that promote FMS of children with DCD are recommended.
Aim: To examine the effects of a school-based FMS training program on motor functions, PA and other psychological outcomes.
Methods and procedures: A total of 131 primary children were allocated to FMS training groups (DCD-FMS n = 35, TD-FMS n = 29), which received FMS training (eight weekly 40-min sessions), or to control groups (DCD-C n = 34, TD-C n = 33), which received conventional physical education lessons. Outcome measures, including accelerometer-assessed PA, motor functions, and self-perceived competence and enjoyment, were measured at baseline, 1-week (immediate effect), 3-months (short-term effect) and 12-months (longer-term effect) after the intervention.
Outcomes and results: FMS training resulted in improved FMS proficiency and increased PA and enjoyment of activity participation in children. In particular, the DCD-FMS group reported greater enjoyment over time. Some effects were also evident for both short- and longer-term.
Conclusions and implications: The findings suggest that a school-based FMS training program has the potential to promote physical and psychological health in children with DCD in the long run.

What this paper adds

Studies relating to school-based interventions in children with Developmental Coordination Disorder (DCD) using the International Classification of Function, Disability, and Health for Children and Youth (ICF-CY) are limited. By applying the ICF-CY as a theoretical framework, the present study was an extension of our previous work to examine the immediate, short and longer term effects of a school-based motor skills training on motor skills proficiency, physical activity and psychological outcomes of children with DCD. Our findings confirm the efficacy of a motor skills training and provide a promising avenue for educators and

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rehabilitation professionals to promote active behaviours and well-being in children with DCD in the long run.

1. Introduction

Developmental Coordination Disorder (DCD) is diagnosed in children with movement difficulties that interfere with their daily activities, academic achievement or health, in the absence of any known medical condition or neurological impairment (American Psychiatric Association, 2013). DCD affects approximately 5–6% of school age children and is recognised as one of the most common disorders affecting this age group (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). The incidence of DCD is higher in boys than in girls, with the sex ratio of boys to girls ranging between 3:1 and 4:1 in Hong Kong (Child Assessment Service, 2008). DCD is normally detected in children aged 6–12 years and about 53% of Hong Kong children with DCD are diagnosed at 6–7 years old (Child Assessment Service, 2008). The movement difficulties resulting from DCD affect the physical and psychological health of children (King-Dowling, Missiuna, Rodriguez, Greenway, & Cairney, 2015) and carry into adulthood (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012).

The association between physical activity (PA) and non-communicable diseases, such as obesity, is well established (World Health Organization, 2013). Evidence, however, indicates that compared to typically developing (TD) children, children with DCD participate less in leisure activities (Raz-Silbiger, Lifshitz, Katz, Steinhart, & Cermak, 2015), have higher body mass index and are at higher risk for obesity-related chronic diseases (Hendrix, Prins, & Dekkers, 2014). They are also found to have poorer self-perceived competence (Wright et al., 2019) and quality of life (Zwicker, Missiuna, Harris, & Boyd, 2012). Local studies report similar findings, showing that children with DCD are more obese and demonstrate less diverse, lower intensity activity participation (Fong et al., 2011), and have poorer motor coordination and self-perceived motor competence (Yu et al., 2016a, 2016b). DCD therefore has significant far-reaching impacts on the physical and psychological health of children, so providing timely and effective intervention is important.

Children's PA is shaped by their surrounding environment and the common correlates of PA are self-perceived competence and mastery of movement skills (Sallis, Prochaska, & Taylor, 2000). Fundamental movement skills (FMS) acquired during childhood form the foundation for an active lifestyle (Cohen, Morgan, Plotnikoff, Callister, & Lubans, 2014). A review article indicated close links between FMS and PA in children (Lubans, Morgan, Cliff, Barnett, & Okely, 2010) and motor skills competence and PA have a positive reciprocal relationship (Lima et al., 2017). Recent systematic reviews have indicated that motor skills interventions have moderate effects on motor performance and other psychological performance in children with DCD, but the effects are primarily short term (Smits-Engelsman et al., 2013; Yu, Burnett, & Sit, 2018). While these intervention studies are important, further research is recommended to determine if improved motor functions can translate to increases in other outcomes and be maintained over time as a result of intervention.

The International Classification of Function, Disability, and Health for Children and Youth (ICF-CY) (World Health Organization, 2007) framework has been used in DCD research (Ferguson, Jelsma, Versfeld, & Smits-Engelsman, 2014). According to this model, human functioning is classified into body functions and structure (e.g., problems with motor coordination), activity limitation (an inability to relate to tasks and actions such as moving around) and participation restriction (restricted opportunities for engaging in life situations such as PA participation with peers). This model suggests that individuals can participate more fully in a life situation through the use of interventions targeted at developing their functions. Intervention programs that promote the functional performance or FMS in children through a partnership approach at school and underpinned by a sound theoretical framework are recommended (Yu et al., 2018). However, studies relating to activity and participation in children with DCD using the ICF-CY are limited in both volume and scope (Smits-Engelsman et al., 2013; Yu et al., 2018). Our recent school-based intervention study indicated that FMS training resulted in improved motor performance and self-perceived competence, but not PA in children with DCD (Yu et al., 2016a). This study, however, employed a quasi-experimental design, included a relatively small sample size (N = 84), and only examined immediate (post-test) and short-term (6-week) effects.

The present study was an extension of our previous work, and examined the immediate, short and longer term effects of FMS training on motor skills proficiency, PA and psychological outcomes of children with DCD by applying the ICF-CY as a theoretical framework. We hypothesized that children who received FMS training would improve their motor skills proficiency as a primary outcome, and have higher levels of PA and perceived competence and enjoyment as secondary outcomes, when compared to those receiving conventional physical education. We also hypothesized that there would be carryover effects in the short and/or longer term and the effects would be more robust in children with DCD than those with TD.

2. Methods

This study was an intervention study utilizing a randomized controlled trial (RCT), with one baseline assessment prior to intervention, and three subsequent assessments 1-week (immediate), 3-months (short-term), and 12-months (longer-term) after the intervention. The study was approved by the Joint Chinese University of Hong Kong-New Territories East Cluster Clinical Research Ethics Committee.

2.1. Participants

Eligible participants were Hong Kong Chinese boys and girls aged between 6–10 years. Inclusion criteria were children with normal or appropriately corrected visual acuity, and exclusion criteria were those with neurological or intellectual impairments or

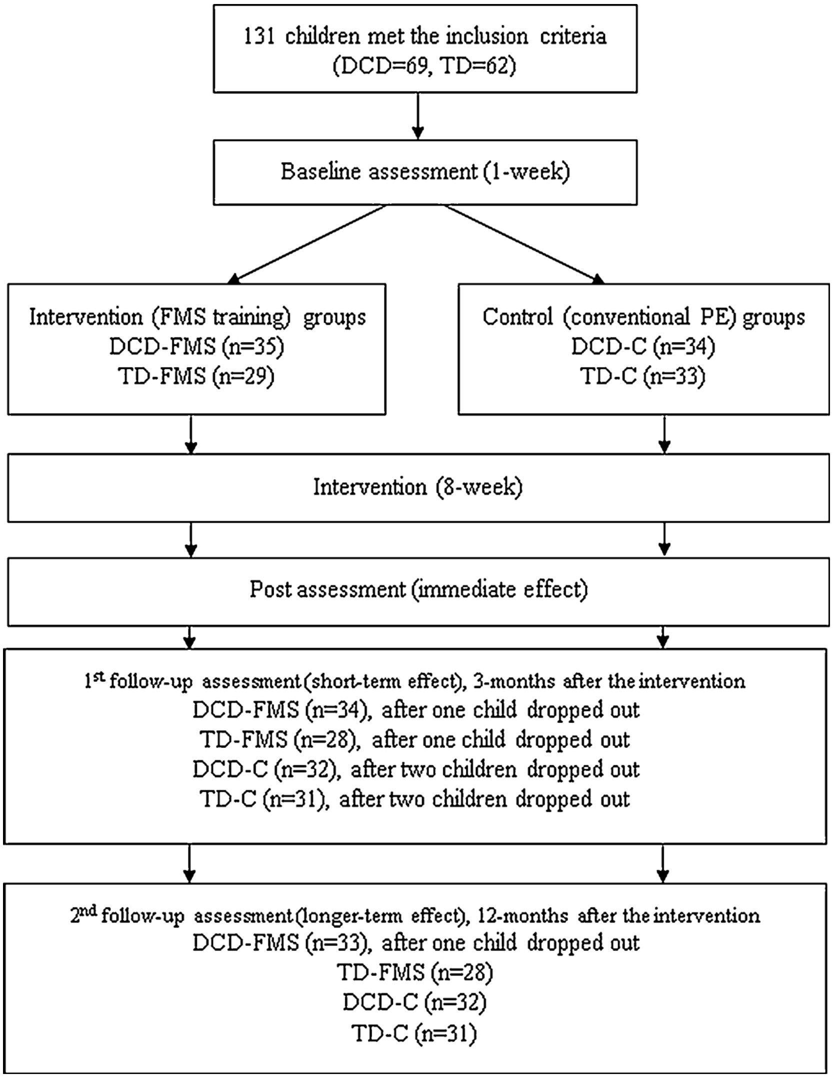

Fig. 1. Flow chart of the participants. TD = children with typical development; DCD = children with developmental coordination disorder; FMS = fundamental movement skills; PE = physical education.

medical conditions that limited participation. A total of 1202 children were initially recruited from three regular primary schools to receive screening tests of DCD with parental consent according to the *Diagnostic and Statistical Manual of Mental Disorder* diagnostic criteria. Movement Assessment Battery for Children-2 (MABC-2) (Henderson, Sugden, & Barnett, 2007) was used to assess motor competence. Children with the 5th percentile cut-off for MABC-2 total score, confirmed by teachers and/or parents using MABC-2 Checklist or the Caregiver Assessment of Movement Participation or both, were considered as having DCD. After screening tests, 113 children (75 boys, 66%) were identified as DCD (i.e., at or below the 5th percentile on the MABC-2), 104 (67 boys, 64%) were identified as at-risk for DCD (i.e., 6–15th percentile), and 985 (446 boys, 45%) were identified as typically developing (i.e., 16th percentile or above). With parental consent, 69 children with DCD, aged between 6 and 10 years, and an age-matched group of 62 children with TD was recruited. This sample size was able to achieve 90% power with a p level of .05 (two-tailed) to detect a significant group difference with an effect size of 0.40 (Niemeijer, Smits-Engelsman, & Schoemaker, 2007). Participants were randomly allocated to either the experimental group (which received multi-skills FMS training) or the control group (which received conventional physical education lessons) after stratification by sex. Four participant groups were then formed: DCD-FMS (children with DCD who received FMS training), TD-FMS (children with TD who received FMS training), DCD-C (children with DCD who received conventional physical education lessons), and TD-C (children with TD who received conventional physical education lessons). Fig. 1 shows a flow diagram outlining participant recruitment and allocation.

2.2. Measures

Several instruments were used in this study.

2.2.1. FMS proficiency

FMS proficiency was assessed with the Test of Gross Motor Development-second edition (TGMD-2) (Ulrich, 2000), which has been used in children with DCD (Yu et al., 2016a, 2016b). The TGMD-2 is a process-oriented test to measure gross motor skills, including locomotor and object control skills. It examines the quality of movement patterns based on a number of qualitative criteria (3–5, depending on a specific skill). The presence or absence of a criterion is scored 1 or 0, yielding a maximum score of 3–5 per trial. Higher scores represent better FMS proficiency. In this study, five FMS skills were included (running, jumping, catching, kicking, throwing). The skill scores were summed to generate subtest scores of locomotor skills (running + jumping) and object control skills (catching + kicking + throwing). All assessments were conducted by trained research assistants during physical education classes at schools.

2.2.2. Physical activity levels

Children's PA levels were objectively assessed for a week using an ActiGraph activity monitor (GT3X), which has been widely used in children, including those with DCD (Yu et al., 2016a). Activity counts were indicated by the original accelerometer data; continuous counts of zero for ≥ 20 min were defined as non-wear times. Days with a total valid monitoring time of < 5 h or > 18 h were excluded and data were analyzed for those who met the required minimum requirement (monitored for ≥ 3 days) of valid PA data. The time spent in sedentary (≤ 100 counts/min), light PA (LPA, 101–2295 counts/min), and moderate-to-vigorous PA (MVPA) (≥ 2296 counts/min) were calculated using the cutoff points (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008). The time spent in sedentary, LPA, and MVPA were further converted and presented as percentages (%) of monitored time in order to account the variance of average monitoring time among participants.

2.2.3. Self-perceived competence

Children's perceived competence in PA was assessed with the subscale of general physical self-concept of the Chinese Version of Physical Self-Descriptive Questionnaire (PSDQ) (Marsh, Hau, Sung, & Yu, 2007). There were six items in this subscale, measured on a 6-point Likert scale, with higher scores representing better self-perceived competence. A composite score of self-perceived competence was obtained. The internal consistency for this subscale was good ($\alpha = 0.89$).

2.2.4. Diversity and enjoyment of participation

Diversity and enjoyment of children's participation in five types of activities (recreational, physical, social, skill-based, and self-improvement) during leisure time was assessed using the Children's Assessment of Participation and Enjoyment (CAPE) (King et al., 2003). Higher score indicates greater enjoyment and diversity. A composite score consisting of all the five activity types was obtained for diversity and enjoyment of participation, respectively.

2.2.5. Physiological profiles

Children's body height (cm) and weight (kg) were measured and their body mass index (BMI; kg/m^2) was calculated. Body weight status (i.e., normal, overweight, obesity) of each child was determined by using sex- and age-adjusted cut off points (Cole, Bellizzi, Flegal, & Dietz, 2000).

2.3. Intervention (FMS training program)

The intervention period was of 8-week duration. It was conducted for 40 min in each week during physical education classes at schools. The experimental group received a training program focusing on the practice of five specific FMS skills (running, jumping, catching, kicking, throwing). The FMS training underlined an approach to motor learning that reduced the occurrence of errors during practice (Capio, Poolton, Sit, Eguia, & Masters, 2013; Capio, Poolton, Sit, Holmstrom, & Masters, 2013; Yu et al., 2016a). The number of practice errors was controlled by manipulating task difficulty. The FMS tasks were therefore designed to initially be very easy with the difficulty progressively increasing over time. Task difficulty was controlled by progressively increasing distance in four skills: jumping (horizontal distance between the take-off and landing points), catching (distance between the thrower and the child), kicking (distance between the stationary ball and the target goal), and throwing (distance between the participant and the target wall). Task difficulty was also controlled by adjusting the size or weight of objects: jumping (height of barriers), catching (size and weight of the balls), kicking (width of the goals), and throwing (size of the target areas). If participants had successfully completed $> 50\%$ of the target skills required in each session, they progressed to the next level of difficulty. Children who were allocated to a control condition received conventional physical education classes as scheduled by the school.

2.4. Data analysis

Data were analyzed using SPSS 23.0. Descriptive statistics including means, standard deviations, frequencies, and percentage were obtained for all variables. Factorial multivariate analysis of covariances (MANCOVAs) or chi-square tests were used to compare participant characteristics and all outcome variables across study groups (i.e., DCD-FMS, TD-FMS, DCD-C, TD-C) at baseline where

Table 1
Descriptive statistics (mean ± SD) for participant characteristics and outcome variables at baseline.

Variable	Intervention groups (*n* = 64)		Control groups (*n* = 67)	
	DCD-FMS	TD-FMS	DCD-C	TD-C
Number (boys)	35(25)	29(17)	34(22)	33(18)
Age (year)	8.2 ± 1.2	8.7 ± 1.2	8.4 ± 1.1	8.6 ± 1.3
Body height (cm)	133.6 ± 8.7	136.1 ± 8.7	134.4 ± 7.8	136.4 ± 10.4
Body weight (kg)	32.2 ± 8.7	33.6 ± 9.8	33.8 ± 9.4	32.0 ± 9.7
BMI (kg/m^2)	17.8 ± 3.3	17.9 ± 3.8	18.4 ± 3.6	16.9 ± 3.2
FMS proficiency				
Running	6.2 ± 1.8	6.9 ± 1.6	6.7 ± 1.5	6.9 ± 1.5
Jumping**	4.9 ± 2.0	6.1 ± 1.6	4.2 ± 2.1	6.0 ± 1.6
Catching*	4.1 ± 1.7	5.1 ± 1.4	3.9 ± 1.8	4.5 ± 1.9
Kicking	6.7 ± 1.3	6.8 ± 1.3	6.2 ± 1.3	6.5 ± 1.3
Throwing	5.9 ± 2.3	6.8 ± 1.3	4.6 ± 2.5	6.5 ± 1.3
Locomotor**	11.1 ± 3.0	13.0 ± 2.3	10.9 ± 2.7	12.9 ± 2.1
Object control*	16.7 ± 3.7	17.8 ± 3.2	15.1 ± 3.6	17.0 ± 3.5
PA (in min): Weekdays				
Valid wearing time	784.7 ± 143.8	768.9 ± 132.8	79.2.2 ± 122.2	841.0 ± 119.9
Sedentary	411.9 ± 119.4	525.5 ± 90.9	440.8 ± 106.1	483.2 ± 126.1
Light PA	348.2 ± 97.5	318.0 ± 91.2	325.8 ± 76.2	335.0 ± 65.7
MVPA	24.6 ± 18.6	25.4 ± 19.8	25.7 ± 15.5	22.8 ± 14.9
PA (in min): Weekend days				
Valid wearing time	692.5 ± 121.1	670.1 ± 90.0	715.2 ± 104.9	745.5 ± 126.5
Sedentary	337.6 ± 95.3	373.4 ± 62.5	382.3 ± 78.6	422.2 ± 130.3
Light PA*	332.2 ± 79.8	277.0 ± 72.7	307.0 ± 96.7	302.2 ± 85.4
MVPA	22.6 ± 23.2	19.7 ± 17.2	25.9 ± 18.6	21.1 ± 21.8
Self-perceived competence	4.4 ± 1.3	4.3 ± 1.3	4.6 ± 1.4	4.5 ± 1.3
Diversity of participation**	21.3 ± 8.3	26.9 ± 7.0	22.9 ± 8.4	28.1 ± 8.7
Enjoyment of participation	3.6 ± 0.8	3.6 ± 0.6	4.0 ± 0.7	4.0 ± 0.5

DCD-FMS = children with DCD who received fundamental movement skills training; TD-FMS = children with typical development who received fundamental movement skills training; DCD-C = children with DCD who performed regular physical education class; TD-C = children with typical development who performed regular physical education class; FMS = fundamental movement skills; PA = physical activity; MVPA = moderate to vigorous PA.

* $p < .05$.

** $p < .001$ for significant group main effect (DCD vs TD).

appropriate. Given that Generalized Linear Mixed Models (GLMM) can handle multilevel data with repeated measures, they were used to determine differences in all outcome variables, with two between-subject factors: experimental condition (intervention vs. control) and group (DCD vs. TD), and the three interactions (experimental condition × group, experimental condition × time, experimental condition × group × time) on all outcome variables as fixed effects. The covariance structure type is unstructured in the models and the random effect for schools was considered in the GLMM analyses with variance components being the covariance structure type to control the variance caused by school clusters (Hedeker, 2005). All effect analyses were also adjusted for age, sex and BMI as confounders. To account for the variance of average monitoring time among participants, percentage (%) of time spent in different PA levels was used in the GLMM analyses. Statistical significance was set at $p < .05$.

3. Results

Table 1 presents the descriptive statistics for participant characteristics and all outcome variables at baseline. There were no significant differences in terms of number, sex distribution, age, body height, body weight, and BMI across study groups (all $p > .05$). Personal factors such as age, sex, and BMI have been reported as confounders (Capio, Sit, Eguia, Abernethy, & Masters, 2015; Yu et al., 2016a) and these variables were considered in the subsequent analyses. Compared to children with TD, children with DCD had significantly poorer FMS proficiency, higher % light PA on weekend days and lower diversity of participation. There were no significant group by experimental condition interaction effects for all outcome variables.

3.1. Changes in the outcome variables

3.1.1. FMS proficiency, PA levels, and self-perceived competence

Table 2 presents the results of GLMM analysis on FMS proficiency, %MVPA on weekdays and weekend days and self-perceived competence. There were significant main group effects for jumping ($p < .01$), throwing ($p < .05$), locomotor skills ($p < .01$), and object control skills ($p < .05$), with children with DCD having significantly poorer FMS proficiency than children with TD. The

Table 2
Comparisons of FMS proficiency, %MVPA and self-perceived competence across the study groups (mean coefficient).

Effect	FMS proficiency							%MVPA		SPC
	Running	Jumping#	Catching	Kicking	Throwing†	Locomotor	Object control	Weekday‡	Weekend	
Experimental condition										
Control(C)	0	0	0	0	0	0	0	0	0	0
FMS training	0.163	0.161	0.648	0.270	−0.120	0.291	0.821	0.253	0.045	−0.261
Group										
TD	0	0	0	0	0	0	0	0	0	0
DCD	−0.004	−1.554**	−0.457	0.092	−1.390*	−1.629**	−1.668*	0.010	0.666	−0.109
Experimental condition × Time										
FMS-baseline	0	0	0	0	0	0	0	0	0	0
FMS-post	0.310	0.759*	−0.172[a]	0.621[a]	0.655	1.069*	1.103 [a]	1.187**	0.678	−0.002
FMS-1st FU	−0.508	0.380	0.618	−0.351	0.380	−0.098	0.662	1.237*	2.060**	0.060
FMS-2nd FU	0.392	0.113	0.575	0.142	0.747 [a]	0.517	1.148*	2.182**	1.086	−0.277
C-baseline	0	0	0	0	0	0	0	0	0	0
C-post	0.273	0.727*	0.545	0.848**	0.485	1.000*	1.879**	0.458	0.189	0.024
C-1st FU	−0.151	1.024**	1.126***	0.081	0.242	0.848 [a]	1.417*	1.206*	0.329	0.112
C-2nd FU	0.645*	0.236	0.902**	0.574	0.723 [a]	0.888 [a]	2.211**	1.437*	−0.048	−0.041

Note: The mean coefficient represents the magnitude of changes in the outcomes when compared to the reference group (coded as 0).
FMS = fundamental movement skills; MVPA = moderate-to-vigorous physical activity; SPC = self-perceived competence; TD = children with typical development; DCD = children with developmental coordination disorder; 1st FU = first follow-up (3-months post intervention); 2nd FU = second follow-up (12-months post intervention); *p < .05; **p < .01, ***p < .001; [a] 0.05 < p < 1.0.
Significant experimental condition × group × time interactions: #DCD-C-post = .890, p < .05; †DCD-C-post = 1.280, p < .05; ‡DCD-C-post = 1.213, p < .05 when compared to DCD-C-baseline.

coefficient value represents the magnitude of difference between a comparison group and a reference group (coded as 0). For example, the result of object control skills (B= −1.668) indicated that the DCD group had 1.668-unit lower score in object control skills when compared to the TD group. There were significant *experimental condition* × *time* interaction effects for all outcomes of FMS proficiency. Specifically, FMS groups (i.e., DCD-FMS, TD-FMS) showed significant improvements in jumping (p < .05) and locomotor skills (p < .05) at post-test and in object control skills (p < .05) at 12-months post-intervention when compared to baseline. In contrast, Control groups (i.e., DCD-C, TD-C) also had significant improvements in certain outcomes at post-test (jumping, p < .05; kicking, p < .01; locomotor skills, p < .05; object control skills, p < .01), 3-months post-intervention (jumping, p < .01; catching, p < .001; object control skills, p < .05), and 12-months post-intervention (running, p < .05; catching, p < .01; object control skills, p < .01) when compared to baseline. Furthermore, there was a significant *experimental condition* × group × *time* interaction effect on jumping and throwing with significant differences being observed in the DCD-C group whose performance in the two skills were significantly improved at post-test when compared to baseline (both p < .05).

Additionally, there were significant *experimental condition* x *time* interaction effects for %MVPA on weekdays and weekend days. FMS groups were found to have higher %MVPA on weekdays at post-test (p < .01), 3-months (p < .05) and 12-months (p < .01) post intervention; and on weekend days at 3-months (p < .01) post intervention. The Control groups were also found to have higher %MVPA on weekdays at 3-months and 12-months post intervention (all p < .05). There was a significant *experimental condition* × *group* × *time* interaction effect for %MVPA on weekdays with one significance difference being found in the DCD-C group who had a higher %MVPA at post-test when compared to baseline (p < .05). No significant main or interaction effects were obtained for self-perceived competence.

3.1.2. Diversity and enjoyment of participation

Table 3 presents the results of GLMM analysis on diversity and enjoyment of participation in overall, recreational, physical, social, skill-based and self-improvement activities. There were significant *experimental condition* × *time* interaction effects for diversity of participation. FMS groups in general decreased their diversity of participation in all activities at post-test (except for skill-based activities), 3-months (except for self-improvement activities) and 12-months post intervention when compared to baseline. Similar patterns were also found in the Control groups over time. There was a significant *experimental condition* × *group* × *time* interaction effect for enjoyment of physical participation in the DCD-FMS group who reported greater enjoyment at post-test (p < .05), 3-months (p < .05) and 12-months (p < .01) post intervention when compared to baseline.

4. Discussion

The ICF-CY model is a useful framework to guide and examine the effectiveness of interventions in terms of conceptual perspectives and targeted outcomes in populations such as children with DCD. Motor skill interventions (MSIs) have been used to enhance motor performance and improve other problems linked to motor impairments in children with DCD (Lucas et al., 2016; Yu et al., 2018).

Table 3
Comparisons of diversity and enjoyment of participation across the study groups (mean coefficient).

Effects	Overall		Recreational		Physical		Social		Skilled-based		Self-improvement	
	D	E	D	E	D	E[#]	D	E	D	E	D	E
Experimental condition												
Control(C)	0	0	0	0	0	0	0	0	0	0	0	0
FMS training	−0.253	−0.367*	−0.007	−0.271	−0.521	−0.177	−0.085	**−0.465***	0.429	−0.393	−0.076	−0.314
Group												
TD	0	0	0	0	0	0	0	0	0	0	0	0
DCD	−2.933	−0.050	−0.152	−0.094	−1.004[a]	0.040	−0.661	−0.321	−0.360	−0.138	−0.809[a]	0.248
Experimental condition × Time												
FMS-baseline	0	0	0	0	0	0	0	0	0	0	0	0
FMS-post	**−4.759****	0.097	**−1.103***	0.207	**−1.069***	−0.050	**−0.931***	0.130	−0.724[a]	0.140	**−0.931****	0.020
FMS-1st FU	**−6.398*****	0.065	**−1.675*****	0.073	**−1.213****	−0.034	**−1.313****	0.264	**−1.506*****	0.165	−0.668[a]	−0.092
FMS-2nd FU	**−9.904*****	−0.039	**−2.897*****	0.163	**−1.457****	−0.078	**−2.457*****	0.060	**−1.140***	−0.198	**−1.895*****	−0.352
C-baseline	0	0	0	0	0	0	0	0	0	0	0	0
C-post	**−5.893*****	−0.088	**−1.092***	−0.078	**−1.200****	0.072	**−1.451****	−0.140	**−1.014***	−0.050	**−1.126****	−0.100
C-1st FU	**−7.713*****	−0.112	**−1.225****	−0.070	**−2.033*****	0.119	**−1.739*****	−0.214	**−0.998***	0.020	**−1.649*****	−0.318[a]
C-2nd FU	**−11.791*****	−0.047	**−2.494*****	0.209	**−2.477*****	0.070	**−3.076*****	−0.071	**−1.255***	−0.085	**−2.147*****	−0.320

Note: The mean coefficient represents the magnitude of changes in the outcomes when compared to a reference group (coded as 0).
D = diversity; E = enjoyment; FMS = fundamental movement skills; TD = children with typical development; DCD = developmental coordination disorder; 1st FU = first follow-up (3-months post intervention); 2nd FU = second follow-up (12-months post intervention); *$p < .05$; **$p < .01$; ***$p < .001$; [a] $.05 < p < 1.0$.
[#] Significant experimental condition × group × time interaction: DCD-FMS-Post = 0.514, $p < .05$, DCD-FMS-1st FU = 0.583, $p < .05$, DCD-FMS-2nd FU = 0.837, $p < .01$ when compared to DCD-FMS-baseline.

Previous studies have indicated that an intervention targeting FMS proficiency of children results in improved motor skills and activity accrual in children (Capio et al., 2015; Lubans et al., 2010; Yu et al., 2016a). As hypothesized, results of the present study indicated that FMS training improved both locomotor and object control skills and time spent in MVPA in children with DCD and TD, and such improvements such as in object control skills were even evident 12-months after the intervention. Previous studies have indicated that targeting FMS proficiency of children results in improved motor skills and activity accrual in children (Capio et al., 2015; Lubans et al., 2010; Yu et al., 2016a). Though the efficacy of FMS training was not robust in children with DCD, the finding of the present study was not surprising as FMS competency is a primary focus of physical education (PE) curricula in Hong Kong primary schools. Since 2013, the Physical Education Section of the Hong Kong Education Bureau has set up the Fundamental Movement Learning Community (FMLC), which aims to enhance the knowledge and skills that primary PE teachers have for teaching fundamental movements skills (Physical Education Section, 2016). This suggests that conventional PE classes appear to be equally effective for improving FMS proficiency of both groups of children. The content taught in conventional PE classes involves considerable FMS practice, with elements similar to those delivered in our FMS training, which helps facilitate FMS proficiency and active behaviour in children. This study showed that, although both FMS training and conventional PE classes had similar effects on improved FMS proficiency, FMS training was superior for promoting MVPA in children. In particular, FMS groups were found to spend more time in MVPA on both weekdays and weekend days, but this was not the case in the Control groups, suggesting its effectiveness to promote activity accrual in children (Capio et al., 2015).

Interestingly, this study found that children with DCD increased their enjoyment of participation in PA during leisure time, an effect that was even sustained for as long as 12 months. Using the errorless motor learning model, which constrains the environment to minimize the amount of practice errors, enables participants to experience a sense of mastery and success (Capio, Poolton, Sit, Eguia et al., 2013; Capio, Poolton, Sit, Holmstrom et al., 2013; Yu et al., 2016a). This suggests that this type of learning model is able to accommodate their variations of motor ability, which may in turn promote feelings of success and enjoyment in PA participation (Capio et al., 2015). However, it was found that children's diversity of participation decreased over time. This finding was consistent with previous studies, which showed that children with DCD decreased participation in school and community settings (Izadi-Najafabadi, Ryan, Ghafooripoor, Gill, & Zwicker, 2018) and had limited diversity of participation in physical, skill-based, informal and overall leisure activities (Jarus, Lourie-Gelberg, Engel-Yeger, & Bart, 2011). Our recent local study showed that Hong Kong children tended to adopt a sedentary lifestyle and had high levels of participation in screen-based activities (Huang et al., 2018). Conjecture about whether this lifestyle would distract them from participating in activities requires further investigation.

Taken together, based on the ICF-CY model and the errorless motor learning approach, the findings of this study showed that the motor skills intervention targeting FMS improved not only FMS proficiency, but also activity levels and enjoyment of activity participation in children with DCD. Some of these gains were even sustained for 12 months, therefore providing a promising avenue to promote physical and psychological health in the long run. This study has several strengths, which include an RCT design with sufficiently large sample, examination of both short- and longer-term effects, high participant compliance rates, and the use of accelerometer assessed PA.

This study has limitations that need to be addressed in future investigations. First, participants were recruited from three regular primary schools in the New Territories of Hong Kong, limiting the generalizability to other primary schools. Second, the measures of FMS were limited to five motor skills. Third, the contents of conventional physical education classes in the three schools were designed and implemented by their own physical education teachers, and participants in the control condition might have experienced more than five skills.

5. Conclusion

Using the ICF-CY model as a theoretical framework, the results of the present study indicate that our FMS training program was effective for promoting FMS proficiency as a primary outcome, and active behaviour as well as enjoyment as secondary outcomes in children. Error-reduced learning requires little involvement of working memory (Maxwell, Capio, & Masters, 2017). As children with DCD have deficits in visual-spatial working memory (Alloway & Warner, 2008), our findings suggest that using the error-reduced learning paradigm as an approach for FMS training provides a promising avenue for educators and rehabilitation professionals working with children with DCD.

Conflict of interests

The authors have no conflict of interests to declare.

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