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Effects of Fundamental Movement Skills Training on Children With Developmental Coordination Disorder

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The purpose of this study was to examine the effects of fundamental movement skills (FMS) training on FMS proficiency, self-perceived physical competence (SPC), physical activity (PA), and sleep disturbance in children with developmental coordination disorder (DCD) compared with children with typical development (TD). A total of 84 children were allocated into either experimental group ($DCD_{[exp]}$, $TD_{[exp]}$) who received 6 weeks of FMS training or control groups ($DCD_{[con]}$, $TD_{[con]}$). FMS were assessed using the Test of Gross Motor Development-2, whereas PA was monitored using accelerometers. SPC and sleep disturbance were evaluated using questionnaires. Results showed that the $DCD_{[exp]}$ group had significantly higher scores in FMS and SPC compared with the $DCD_{[con]}$ group at posttest. The $DCD_{[exp]}$ group scored lower in sleep disturbance at follow-up when compared with posttest. It is suggested that short-term FMS training is effective in improving FMS and SPC and reducing sleep disturbances for children with DCD.

***Keywords*:** perceived competence, sleep, intervention

Developmental coordination disorder (DCD) is diagnosed in children with poor motor coordination that interferes with their academic achievements or activities of daily living (American Psychiatric Association [APA], 2000). Children with DCD exhibit delays in motor skills (Willoughby & Polatajko, 1995) such as fundamental

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movement skills (FMS), which are the foundation for developing future specialized and context-specific movements (Burton, 1998). Further, children with DCD are more obese and are at a higher risk of developing obesity-related chronic diseases (Hendrix, Prins, & Dekkers, 2014).

Despite the well-known health benefits of physical activity (PA), children with DCD are less likely to be physically active than their typically developing peers (Cairney, Hay, Veldhuizen, Missiuna, & Faught, 2010). It has been suggested that children with DCD tend to avoid or withdraw from PA because of low levels of self-perceived physical competence (SPC) (Jarus, Lourie-Gelberg, Engel-Yeger, & Bart, 2011). In addition to physical and psychological health, sleep habits in children with DCD are known to be impacted as well. A recent study by Barnett & Wiggs (2012) found that children with DCD experienced more sleep disturbance (e.g., daytime sleepiness) than children with typical development (TD). Evidence from longitudinal studies indicates that the motor problems of children with DCD can persist into adolescence (Cairney et al., 2010; Cantell, Smyth, & Ahonen, 1994). Therefore, children with DCD should be targeted for intervention to help reduce secondary conditions and improve activity participation.

Motor skills cannot develop well without learning and practice (Logan, Robinson, Wilson, & Lucas, 2012). Given that, early interventions that improve motor proficiency are particularly important for children with DCD. To examine the effectiveness of motor skill interventions in improving FMS proficiency in children, including those with disabilities, Logan et al. (2012) synthesized the findings from 25 studies via a meta-analysis. They found that children who received a motor skill intervention demonstrated significant improvements in FMS proficiency with a moderate effect size (d = 0.39) being reported. Significant improvements were not evident for controls (d = 0.06). This finding supports the notion that motor skill intervention is an effective strategy to improve FMS competence in children. It is recommended that the implementation of motor training programs for children should be underpinned by a sound theoretical framework to increase their effectiveness (Riethmuller, Rachel, & Okely, 2009). For example, in a recent meta-analysis by Smits-Engelsman et al. (2013), task-oriented and motor-training-based intervention was among the most effective training approaches to improve motor performance of children with DCD. The principle of this type of intervention is to focus on learning particular motor skills and improves specific aspects of task performance that are causing an individual's motor difficulty (Smits-Engelsman et al., 2013). Previous studies have determined the effectiveness of task-oriented motor skill (focusing on FMS) intervention in improving FMS proficiency in children with DCD (e.g., Ferguson, Jelsma, Jelsma, & Smits-Engelsman, 2013; Miyahara & Wafer, 2004; Niemeijer, Smits-Engelsman, & Schoemaker, 2007).

Meanwhile the children and youth version of the International Classification of Functioning, Disability, and Health (ICF-CY) model has been useful for identifying potential points of interventions for children, including those with disabilities (World Health Organization, 2007). It is a biopsychosocial model in helping to understand human functioning with three interrelated components, namely, body functions and structure, activity, and participation. This model also includes contextual (personal and environment) factors that interact with the three components of human functioning. The developers of the ICF-CY model highlight that individuals can participate more fully in a given life situation after having undergone interventions, and intervention at one component (e.g., activity) may influence another component (e.g., participation) (Bornman, 2004). According to this model, interventions in children should aim to improve children's inherent abilities (e.g., motor proficiency) and their performance in daily activities (e.g., PA, sleep) in a familiar environment (e.g., school) with considering children's personal factors (e.g., age, sex, body fat, psychological profile) (Bjorck-Akesson et al., 2010; Simeonsson et al., 2014).

The ICF-CY model has been widely used in children with and without disabilities (including DCD) (Capio, Sit, Eguia, Abernethy, & Masters, 2015a; Dunford, 2011; Iversen, Ellertsen, Tytlandsvik, & Nodland, 2005). In a previous study, it was found that children with TD who are competent in FMS are more likely to perceive themselves as having good physical competence (Rudisill, Mahar, & Meaney, 1993). A positive relationship between FMS and SPC has been recently confirmed in children with DCD (Yu et al., 2015). Moreover, it has been well known that motor skills are positively related to habitual behaviors such as PA participation (Stodden et al., 2008). In addition, the existence of a positive relationship between motor proficiency and sleep quality (with sleep disturbance as an outcome measure) has been reported in children with DCD in a prior study (Barnett & Wiggs, 2012). However, the effectiveness of motor skill training (emphasizing FMS) on promoting SPC, PA, and sleep behaviors in children with DCD still needs to be determined.

In addition to the task-oriented approach and the ICF-CY model, an implicit motor learning approach has been found suitable for motor skills training of children with lower skills proficiency (Capio, Poolton, Sit, Eguia, & Masters, 2013a). This learning approach suggests that motor skills can be acquired with limited accumulation of declarative knowledge (Masters & Maxwell, 2004). One of the paradigms used to promote implicit motor learning in children is errorless learning (Maxwell, Masters, Kerr, & Weedon, 2001). Referred to as error-reduced learning in other literature (e.g., Capio, Poolton, Sit, Eguia, & Masters, 2013a), this approach manipulates the environment such that practice errors are minimized. Greater success during practice of a motor skill diminishes the need for learners to consciously monitor and correct movements, suggesting limited dependence on cognitive resources (Maxwell et al., 2001). It has been suggested that error-reduced learning tends to be less dependent on working memory resources compared with more traditional (or error-strewn) motor learning approaches. This notion is supported by previous findings that indicate that errorless motor learners are able to perform a cognitively demanding secondary task without affecting their motor performance, whereas the performance of "errorful" learners deteriorates (Maxwell et al., 2001). Several studies had shown that error-reduced learning conditions tend to be beneficial for children with physical and intellectual disabilities (Capio et al., 2013a, et al., 2015a, 2015b). It is likely that such an approach may be effective in promoting FMS development in children with DCD.

The present study aimed to examine the effects of a task-oriented motor skill (focusing on FMS) training program using an error-reduced learning strategy on FMS proficiency, SPC, PA) and sleep disturbance in children with DCD and those with TD. We hypothesized that a short-term FMS training would be effective in improving FMS proficiency, SPC, and PA levels and in reducing sleep disturbance in children with DCD. The improvements on all measured outcomes after FMS training were hypothesized to be more sustainable in children with DCD than in children with TD.

Method

The study was a quasi-randomized, controlled, and single blinded trial with repeated measures. Two experimental ($DCD_{[Exp]}$ vs. $TD_{[Exp]}$) and two control ($DCD_{[Con]}$ vs. $TD_{[Con]}$) groups were included in this study. All outcome variables were measured at baseline, immediately (posttest) and 6 weeks (follow-up test) after the intervention. The outcome assessors were blinded to group allocation. The study was approved by the Survey and Behavioral Research Ethics Committee of the University.

Participants

Three hundred and twelve Hong Kong Chinese children (7–10 years old) were initially recruited from two regular schools to receive screening tests of DCD with parental consent. According to the *Diagnostic and Statistical Manual of Mental Disorder* (DSM-IV-TR; APA, 2000) diagnostic criteria, those children who met the following criteria were diagnosed as having DCD: (a) a total test score at or below the 15th percentile in the Movement Assessment Battery for Children-Second edition (MABC-2) (Henderson, Sugden, & Barnett, 2007). This cut-off point has been used in previous intervention studies in children with DCD (e.g., Hung & Pang, 2010; Peens, Pienaar, & Nienaber, 2008); (b) teachers reported that poor motor coordination interferes with the child's activities of daily living based on the MABC-2 checklist; and (c) no known medical conditions or neurological impairments were reported by parents. After screening tests, the mean MABC-2 score was 65.9 ± 13.93, ranging from 32 to 97. All children were then categorized into either the broad TD ($n = 246$) or DCD ($n = 66$) group according to the DSM-IV-TR diagnostic criteria.

According to a prior controlled study (Niemeijer et al., 2007), a power calculation indicated that a sample size of 21 participants per group would be required to achieve 90% power with a p level of.05 (two-tailed) to detect a significant group difference with an effect size of.40. Assuming a 20% attrition rate, 26 children were needed in each of the four groups. In the current study, the TD and DCD groups were selected from the TD and DCD sample, respectively. Because some children and their parents' declined to participate in the subsequent intervention study, 47 children with DCD ($DCD_{[Exp]} = 28$; $DCD_{[Con]} = 19$) and 54 children with TD ($TD_{[Exp]} = 24$; $TD_{[Con]} = 30$) were recruited and quasi-randomly assigned to a given group. Due to participant dropouts, only data from 38 children with DCD ($DCD_{[Exp]} = 22$; $DCD_{[Con]} = 16$) and 46 children with TD ($TD_{[Exp]} =17$; $TD_{[Con]} = 29$) were retained for analysis. Of all 38 children with DCD, 63% (24: $DCD_{[Exp]} = 10$, $DCD_{[Con]} = 14$) were at or below 5th percentile of MABC-2 total score and 37% (14: $DCD_{[Exp]} = 6$, $DCD_{[Con]} = 8$) fell between the 6th and 15th percentile. Those children who had been diagnosed as having other disabilities (e.g., attention deficit hyperactivity disorder) and had a known health condition (e.g., injury) that would contraindicate their engagement in PA were excluded from the study.

Body height and weight of each participating child were assessed by trained research assistants during physical education (PE) class. Demographic information (e.g., date of birth) was obtained from the parents.

Intervention

The intervention period was of 6-weeks duration. The control groups performed their regular PE classes whereas the experimental groups received a replacement program (group-based multiskill FMS training) during PE classes. The FMS training program was conducted 35 min (including warm-up and cool-down) per session, twice per week. All the children completed a total of nine sessions of FMS training over 6 weeks during the intervention period. In previous studies, interventions lasting for 6–8 weeks generated positive effects on motor proficiency (Hung & Pang, 2010) and self-concept (Peens et al., 2008) in children with DCD. Participants in the experimental groups were instructed to practice five skills (i.e., running, jumping, catching, kicking, and throwing) underpinned by error-reduced learning paradigm. To reduce the number of errors, the FMS tasks were designed to initially be very easy with the difficulty progressively increasing over time (Capio, Poolton, Sit, Holmstrom, & Masters, 2013b). To control the task difficulty, either the distance was increased (running, jumping, and catching) or the target area was progressively narrowed (kicking and throwing). Table 1 shows the details and levels of difficulty for each skill in the FMS training program.

Participants were instructed to attempt to achieve the performance outcome (e.g., throw the beanbag onto the target area) while no instructions on the correct movement patterns were provided to the children. The research assistant recorded the participants' performance for each session. Participants progressed to the next level of difficulty if they had successfully completed >50% of the target skills required in each session. For the first eight sessions, either locomotor skills or object-control skills were practiced with three bouts of five repetitions for each target skill (Table 1). For the last session (i.e., Session 9), all five skills were practiced with two bouts of three repetitions for each skill. All FMS training sessions were led by the first author with assistance from the PE teachers from each school as well as a research assistant.

Outcomes and Measurements

FMS Proficiency. FMS proficiency was measured via the *Test of Gross Motor Development-Second Edition* (TGMD-2) (Ulrich, 2000). The TGMD-2 is a process-oriented FMS measurement that has demonstrated high internal reliability and validity. It has been used in studies involving children with DCD (Slater, Hillier, & Civetta, 2010) and those without DCD (Pang & Fong, 2009) aged 3–10 years. The TGMD-2 examines the quality of movement patterns based on a number of qualitative criteria (3–5, depending on the specific skill). The presence or absence of a criterion is scored 1 or 0, yielding a maximum score of 3–5 per trial, and two trials are administered for each skill. Higher scores represent better FMS proficiency. In this study, five FMS components (running, jumping, catching, kicking, and throwing) were assessed and deemed to be relevant activities for common forms of PA such as sports and recreation in children with and without disabilities (Capio, Sit,

Table 1 Description of Task Components in Nine Sessions of Fundamental Movement Skills Training

	Running	Jumping	Catching	Throwing	Kicking
Task	Run from the start to the finish line.	Horizontally jump from the start to the target line.	Catch a 6-in. ball from the thrower.	Throw a beanbag onto the target area on the wall, standing behind a line that is 4 m away from the wall.	Kick a football into the goal set by 2 cones. The distance from the football to the center of the 2 cones is 6 m.
Task component	Distance between 2 lines	Distance between 2 lines	Distance between participant and thrower	Area of the target	Width of the goal
Task difficulty per session[a]					
Session 1	3 m	0.4 m	—	—	—
Session 2	—	—	0.5 m	1.8 × 1.8 m	3.0 m
Session 3	4 m	0.6 m	—	—	—
Session 4	—	—	1.0 m	1.5 × 1.5 m	2.5 m
Session 5	5 m	0.8 m	—	—	—
Session 6	—	—	1.5 m	1.2 × 1.2 m	2.0 m
Session 7	6 m	1.0 m	—	—	—
Session 8	—	—	2.0 m	0.9 × 0.9 m	1.5 m
Session 9	8 m	1.2 m	2.5 m	0.6 × 0.6 m	1.5 m[b]

[a]The error-reduced learning paradigm was used to constrain the learning environment where practice errors are minimized in the early learning stage. [b]Children were supposed to kick a ball into a 1.0-m-wide goal, but they kept practicing with a 1.5-m-wide goal because they have not successfully completed >50% of practice last session.

Abernethy, & Masters, 2012). The maximum score of the five FMS skills varied from 6 to 8 (running = 8, jumping = 8, catching = 6, kicking = 8, and throwing = 8). The skill scores were summed to generate subtest scores of locomotor skills (running + jumping; maximum score = 16) and object control skills (catching + kicking + throwing; maximum score = 22). All FMS assessments were conducted by trained research assistants during PE lessons at school, with the assistance from PE teachers.

SPC. The Physical Self-Descriptive Questionnaire (PSDQ) was designed to assess an individual's physical self-concept (Marsh, Richards, Johnson, Roche, & Tremayne, 1994) and the Chinese version of the PSDQ was used in the current study (Marsh, Hau, Sung, & Yu, 2007). SPC was measured using the PSDQ with 10 subscales: physical health, physical coordination, body fat, sporting ability, physical self-concept, physical appearance, physical strength, physical flexibility, physical fitness, and global self-esteem (Marsh et al., 1994). A six-point Likert scale is used with higher scores representing better SPC in a specific area. The Chinese version of the PSDQ has been used for Chinese children aged 7–15 years and has demonstrated satisfactory reliability within the subscales, with Cronbach's alpha ranging from .67 to .92 (Marsh et al., 2007). In the current study, the internal consistency for the subscales was acceptable to good (α = .65–.94).

Levels of PA. PA was assessed using the GT3×+ accelerometers (ActiGraph, Pensacola, FL), which have been widely used in children, including those with DCD (Green et al., 2011). Participants wore the accelerometers over a period of 7 consecutive days. The accelerometers were initialized to record data using a 5-s epoch. To enhance compliance with the monitor, parents were asked to record the times when their children put on, or took off, the accelerometers in diaries (Trost, Mciver, & Pate, 2005).

Days with a total monitoring time of <5 and >18 hr were excluded from analysis, and continuous counts of zero for ≥20 min were defined as nonwearing times (Choi, Liu, Matthews, & Buchowski, 2011). Data were analyzed for those who met the required minimum monitoring time of 3 weekdays (Riddoch et al., 2004). The original accelerometer data were activity counts. The average activity counts per minute (counts/min) were used to determine PA volume. The cutoff points suggested by Evenson, Catellier, Gill, Ondrak, and McMurray (2008) were used to calculate the time spent in light PA (101–2,295 counts/min) and moderate-to-vigorous PA (MVPA) (≥2,296 counts/min). These cutoff points have been used in children and youth (Trost, Loprinzi, Moore, & Pfeiffer, 2011) and in children with disabilities (Capio et al., 2015a). To account for the variance of average monitoring time among participants, the time spent in light PA and MVPA were converted and presented in percentage (%) of the monitored time.

Sleep Disturbance. The Children's Sleep Habits Questionnaire—Chinese version (CSHQ-C) was used to assess disturbance that children (4–10 years) experienced during sleep (Liu, Liu, Owens, & Kaplan, 2005). The CSHQ-C includes eight subscales, namely, bedtime resistance (e.g., child is afraid of sleep alone), sleep onset delay (e.g., child is difficult to fall asleep in 20 min), sleep duration (e.g., child sleeps too little), sleep anxiety (e.g., child is afraid of sleeping in the dark), night waking (e.g., child moves to other's bed during the night), parasomnias (e.g., child talks during sleep), sleep-disordered breathing (e.g., child seems to stop breathing during sleep), and daytime sleepiness (e.g., child wakes up in negative mood).

Parents were asked to recall and rate their children's sleep disturbance on a three-point scale. Higher scores represent more sleep disturbance in a given subscale, and the range of score varies in each subscale (bedtime resistance [6–18], sleep onset delay [1–3], sleep duration [3–9], sleep anxiety [4–12], night waking [3–9], parasomnias [7–21], sleep disordered breathing [3–9], and daytime sleepiness [8–24]). The total sleep disturbance score ranging from 33 to 99 is obtained by summing up the scores in all 33 items. CSHQ-C has a high internal consistency (α = .80) for the entire scale and has been used for Hong Kong Chinese children with and without developmental disorders (Liu et al., 2005). In the current study, the internal consistency of the entire scale of CSHQ-C was satisfactory (α = .73).

Data Analysis

Descriptive statistics such as *M*, *SD*, and percentage were presented where appropriate. Chi-square statistics were used to compare the number of children with DCD and children with TD based on sex. Factorial univariate analysis of variance (ANOVA) was used to compare baseline age, height, weight, and body mass index (BMI) among all groups and was corrected using Bonferroni adjustments when needed. Cronbach's alpha was assessed to determine the internal consistency for each subscale of the PSDQ and for the entire scale of the CSHQ-C. A factorial univariate analysis of covariance (ANCOVA) utilizing the baseline score and other key confounders as covariates was used to determine the effects of intervention. The within-subject factor was time (three assessment points: baseline, immediately and 6 weeks after the intervention) and the between-subject factors were group (DCD vs. TD) and experimental condition (experimental vs. control). ANCOVA that utilizes a baseline score as a covariate is recommended because it increases statistical power and precision (Rausch, Maxwell, & Kelley, 2003). Analyses of simple effects and post hoc Bonferroni adjustments were performed after significant interaction effects by overall ANCOVA were confirmed. Partial correlation (*r*) of FMS proficiency with SPC, PA, and sleep disturbance were conducted at two occasions of measurement postintervention in the $DCD_{[Exp]}$ group and the $TD_{[Exp]}$ group, respectively. The effect size (η^2) was included and the effect was considered as small (0.2 or less), medium (0.5), or large (0.8 and above) (Thomas, Nelson, Silverman, 2011). Statistical significance was set at $p < .05$ for all tests.

Results

Baseline Demographic and Anthropometric Characteristics

The experimental groups were significantly younger than the control groups, $p = .003$ (Table 2). Children with DCD were significantly heavier, $p = .001$, and had higher BMI, $p < .001$, than children with TD. Age and BMI were therefore treated as covariates in the subsequent univariate analysis. Because motor competence is varied by sex in children (Rudisill et al., 1993), sex was also considered as a covariate in the subsequent analysis.

Differences Between Children With DCD and TD at Baseline

At baseline, results of ANCOVAs showed that, when compared with children with TD, children with DCD demonstrated poorer locomotor skills, $F(1, 79) = 4.185$, $p = .044$, $\eta^2 = .05$; object-control skills, $F(1, 79) = 20.637$, $p < .001$, $\eta^2 = .21$; catching, $F(1, 79) = 4.811$, $p = .031$, $\eta^2 = .06$; and throwing, $F(1, 79) = 24.985$, $p < .001$, $\eta^2 = .24$. Children with DCD also showed poorer physical coordination, $F(1, 79) = 6.745$, $p = .011$, $\eta^2 = .08$; sporting ability, $F(1, 79) = 10.52$, $p = .002$, $\eta^2 = .12$; physical self-concept, $F(1, 79) = 6.904$, $p = .010$, $\eta^2 = .08$; and physical flexibility, $F(1, 79) = 4.322$, $p = .041$, $\eta^2 = .05$. In addition, they spent more percentage of time in light PA, $F(1, 79) = 5.596$, $p = .020$, $\eta^2 = .07$, and showed higher scores in bedtime resistance, $F(1, 79) = 8.345$, $p = .005$, $\eta^2 = .10$ and sleep anxiety, $F(1, 79) = 7.517$, $p = .008$, $\eta^2 = .09$].

Table 2 Baseline Demographic and Anthropometric Characteristics of Participants

	Sex (girls/boys, *n*)	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m²)
Children with DCD					
$DCD_{[Exp]}$	9/13	8.2 ± 0.75	134.3 ± 7.33	35.2 ± 10.05	19.3 ± 4.23
$DCD_{[Con]}$	4/12	8.9 ± 0.93	137.1 ± 7.95	38.7 ± 11.64	20.2 ± 4.09
Children with TD					
$TD_{[Exp]}$	9/8	8.5 ± 0.62	132.1 ± 7.94	29.3 ± 5.07	16.7 ± 1.72
$TD_{[Con]}$	15/14	8.9 ± 0.88	135.7 ± 8.71	31.1 ± 6.86	16.8 ± 2.51
Statistics[a]	3.68	3.60*	1.24	4.36**	5.93**

Note. BMI = body mass index; DCD = developmental coordination disorder; $DCD_{[Exp]}$ = children with DCD who received fundamental movement skills (FMS) training; $DCD_{[Con]}$ = children with DCD who performed regular physical education class; TD = typical development; $TD_{[Exp]}$ = TD children who received FMS training; $TD_{[Con]}$ = TD children who performed regular physical education class.

[a]Statistics associated with the chi-square test for categorical variables and with analysis of variance for continuous variables.

*$p < .05$. **$p < .01$.

Changes in FMS Proficiency, PA, SPC, and Sleep Disturbance

FMS Proficiency. After controlling for age, BMI, sex, and baseline scores of FMS proficiency, results of the ANCOVAs revealed the following: significant group × experimental condition × time effects in locomotor skills, $F(1, 76) = 5.891$, $p = .018$, $\eta^2 = .07$, and jumping, $F(1, 76) = 5.799$, $p = .018$, $\eta^2 = .07$; group × experimental condition effects for catching, $F(1, 76) = 6.954$, $p = .010$, $\eta^2 = .08$]; *experimental condition* × *time* effects in throwing, $F(1, 76) = 4.354$, $p = .040$, $\eta^2 = .05$; group × time effect in kicking, $F(1, 76) = 6.403$, $p = .013$, $\eta^2 = .08$; and experimental condition main effects in object-control skills, $F(1, 76) = 13.959$, $p < .001$, $\eta^2 = .16$] and kicking, $F(1, 76) = 7.148$, $p = .009$, $\eta^2 = .09$. The interactions were investigated via simple effects to determine the difference in FMS proficiency at posttest and follow-up test.

As shown in Table 3, at posttest, the $DCD_{[Exp]}$ group scored significantly higher in jumping, $F(1, 32) = 4.402$, $p = .044$, $\eta^2 = .12$, and catching, $F(1, 32) = 5.152$, $p = .030$, $\eta^2 = .14$, than the $DCD_{[Con]}$ group. However, the $TD_{[Exp]}$ group scored significantly lower in both locomotor skills, $F(1, 40) = 9.803$, $p = .003$, $\eta^2 = .20$] and jumping, $F(1, 40) = 6.712$, $p = .013$, $\eta^2 = .14$, when compared with the $TD_{[Con]}$ group. Meanwhile experimental groups scored significantly higher in kicking $F(1, 78) = 5.048$, $p = .027$, $\eta^2 = .06$, than control groups. At follow-up, experimental groups scored significantly higher in object-control skills, $F(1, 78) = 17.804$, $p < .001$, $\eta^2 = .19$, and throwing, $F(1, 78) = 14.911$, $p < .001$, $\eta^2 = .16$, than control groups. The $DCD_{[Exp]}$ group scored significantly higher in catching, $F(1, 32) = 5.637$, $p = .024$, $\eta^2 = .15$, compared with the $DCD_{[Con]}$ group.

Table 3 Descriptive Statistics for FMS Proficiency and Physical Activity (PA) Across Groups at Baseline (Pre), Posttest (Post), and Follow-Up (FU), *M*, *SD*

Variable [score]	$DCD_{[Exp]}$ Pre	$DCD_{[Exp]}$ Post	$DCD_{[Exp]}$ FU	$DCD_{[Con]}$ Pre	$DCD_{[Con]}$ Post	$DCD_{[Con]}$ FU	$TD_{[Exp]}$ Pre	$TD_{[Exp]}$ Post	$TD_{[Exp]}$ FU	$TD_{[Con]}$ Pre	$TD_{[Con]}$ Post	$TD_{[Con]}$ FU	Significant difference
Loco-motor [0–16]	12.2, 2.6	13.3, 2.4	13.0, 2.1	9.2, 1.9	10.1, 2.5	12.2, 2.3	12.3, 2.3	12.4, 2.0	13.8, 2.0	12.9, 2.4	14.1, 1.8	14.5, 1.5	Post: $TD_{[Exp]} < TD_{[Con]}$**
Running [0–8]	7.1, 1.2	7.2, 1.0	7.0, 1.3	6.0, 1.1	6.4, 1.0	6.8, 1.5	6.8, 1.2	6.9, 1.3	7.5, 0.8	7.4, 0.9	7.6, 1.0	7.6, 0.7	—
Jumping [0–8]	5.1, 1.9	6.1, 1.9	6.0, 1.2	3.2, 1.68	3.7, 2.0	5.4, 1.4	5.5, 1.8	5.4, 1.8	6.2, 1.6	5.5, 1.9	6.5, 1.7	6.9, 1.4	Post: $DCD_{[Exp]} > DCD_{[con]}$* $TD_{[Exp]} < TD_{[Con]}$*
Object control [0–22]	12.9, 2.7	17.6, 2.8	19.6, 1.7	13.4, 3.1	16.0, 2.1	16.3, 2.6	15.4, 3.8	17.8, 2.9	20.1, 2.2	16.7, 3.5	17.9, 3.0	19.0, 2.3	FU: Exp > Con***
Catching [0–6]	4.0, 1.4	5.2, 0.9	5.5, 0.7	3.7, 1.6	4.2, 1.6	4.3, 1.6	4.5, 1.9	5.4, 0.9	5.2, 1.2	5.0, 1.3	5.3, 1.0	5.4, 0.6	Post: $DCD_{[Exp]} > DCD_{[con]}$* FU: $DCD_{[Exp]} > DCD_{[Con]}$*

(continued)

Table 3 *(continued)*

Variable [score]	$DCD_{[Exp]}$ Pre	Post	FU	$DCD_{[Con]}$ Pre	Post	FU	$TD_{[Exp]}$ Pre	Post	FU	$TD_{[Con]}$ Pre	Post	FU	Significant difference
Kicking [0–8]	6.1, 1.2	7.2, 1.0	7.0, 1.0	5.5, 0.6	6.7, 0.6	6.1, 1.1	6.1, 1.4	7.2, 0.8	7.4, 0.8	6.0, 1.2	6.7, 1.1	6.9, 1.0	Post: Exp > Con*
Throwing [0–8]	2.9, 1.8	5.2, 2.3	7.2, 1.1	4.2, 2.2	5.2, 1.8	5.8, 1.7	4.8, 2.3	5.3, 2.2	7.5, 0.8	5.8, 2.3	5.9, 2.1	6.6, 1.7	FU: Exp > on***
PA volume, counts/ min	460.1, 96.2	431.7, 87.5	393.1, 64.5	464.9, 90.6	439.7, 86.8	439.7, 90.8	414.4, 95.4	395.6, 88.7	396.7, 83.9	450.3, 123.1	443.2, 108.5	419.7, 90.6	$DCD_{[Exp]}$ & $TD_{[Con]}$: Post > FU*
Light PA, %	42.3, 7.0	45.6, 6.8	44.0, 6.7	47.6, 8.8	45.1, 7.7	46.3, 9.1	45.1, 6.7	43.2, 5.7	43.4, 6.3	41.7, 4.8	40.7, 4.9	38.6, 5.5	—
MVPA, %	4.4, 2.0	4.1, 1.6	3.5, 1.6	4.2, 1.8	4.2, 2.3	3.9, 1.6	3.7, 1.8	3.6, 1.8	3.6, 1.8	5.1, 2.6	5.0, 2.4	4.8, 1.9	—

Note. DCD = developmental coordination disorder; $DCD_{[Exp]}$ = children with DCD who received fundamental movement skills training; $DCD_{[Con]}$ = children with DCD who performed regular physical education class; FMS = fundamental movement skills; MVPA = moderate to vigorous physical activity; TD = typical development; $TD_{[Exp]}$ = TD children who received FMS training; $TD_{[Con]}$ = TD children who performed regular physical education class..

*p <. 05. **p < .01. ***p < .001.

PA. After controlling for age, BMI, sex, and baseline scores of PA data, results of the ANCOVAs showed significant group × experimental condition × time effects in PA volume, $F(1, 76) = 4.252$, $p = .043$, $\eta^2 = .05$, and light PA, $F(1, 76) = 5.136$, $p = .026$, $\eta^2 = .06$. Simple effects analyses showed that both the $DCD_{[Exp]}$ group and the $TD_{[Con]}$ group showed significantly lower PA volume at follow-up when compared with posttest, all $p < .05$ (Table 3). However, no significant simple effects were evident in light PA, and no significant main and interaction effects were found in MVPA.

SPC. After controlling for age, BMI, sex, and baseline scores of SPC, results of the ANCOVAs showed a significant group × experimental condition × time effect on physical health, $F(1, 76) = 11.722$, $p = .001$, $\eta^2 = .13$; experimental condition × time effect on physical coordination, $F(1,76) = 8.594$, $p = .004$, $\eta^2 = .10$; and experimental condition main effects on physical strength, $F(1, 76) = 6.863$, $p = .011$, and physical fitness, $F(1,76) = 4.359$, $p = .040$, $\eta^2 = .07$. The interactions were investigated with simple effects to determine the difference in SPC at posttest and follow-up test.

With reference to Table 4, at posttest, experimental groups scored significantly higher on physical coordination, $F(1, 78) = 4.527$, $p = .037$, $\eta^2 = .06$; physical strength, $F(1, 78) = 4.799$, $p = .031$, $\eta^2 = .06$; and physical fitness, $F(1, 78) = 6.463$, $p = .013$, $\eta^2 = .08$, than control groups. The $TD_{[Exp]}$ group scored significantly higher on physical health, $F(1, 40) = 5.523$, $p = .024$, $\eta^2 = .12$, than the $TD_{[Con]}$ group. No significant group difference on SPC was found at follow-up test.

Sleep Disturbance. After controlling for age, BMI, sex, and baseline scores of sleep disturbance, results indicated significant group × experimental condition effect on night waking, $F(1, 76) = 4.326$, $p = .041$, $\eta^2 = .05$, and experimental condition × time effect on total sleep disturbance, $F(1, 76) = 5.544$, $p = .021$, $\eta^2 = .07$. Simple effects analyses indicated that both DCD and TD experimental groups presented significantly lower score in total sleep disturbance at follow-up when compared with posttest, both $p < .05$ (Table 5). However, no significant simple effects were found on night waking.

Associations of FMS Proficiency With SPC, PA, and Sleep Disturbance

Partial correlations of FMS proficiency with SPC variables, PA levels, and sleep disturbance were conducted at two occasions of measurement postintervention in the $DCD_{[Exp]}$ group and the $TD_{[Exp]}$ group, respectively.

At posttest, locomotor skill proficiency was positively related to self-perception of physical coordination ($r = .513$, $p < .05$), sporting ability ($r = .600$, $p < .01$), physical self-concept ($r = .477$, $p < .05$), and physical strength ($r = .524$, $p < 05$) in children with DCD. For children with TD, locomotor skill proficiency was negatively related to physical appearance ($r = –.587$, $p < .05$) and sleep anxiety ($r = –.697$, $p < .01$), and was positively correlated to PA volume ($r = .640$, $p < .05$) and the percentage of time spent in MVPA ($r = .593$, $p < .05$).

At follow-up test, object-control skills proficiency was positively associated with physical appearance ($r = .511$) and sleep anxiety ($r = .469$), and was negatively related to sporting ability ($r = –.470$) in children with DCD (all $p < .05$). For

Table 4 Descriptive Statistics for SPC Variables in All Groups at Baseline (Pre), Posttest (Post), and Follow-Up (FU), *M*, *SD*

Variable [score]	$DCD_{[Exp]}$			$DCD_{[Con]}$			$TD_{[Exp]}$			$TD_{[Con]}$			Significant difference
	Pre	Post	FU	Pre	Post	FU	Pre	Post	FU	Pre	Post	FU	
Physical health [1–8]	5.0, 0.6	4.8, 0.8	5.1, 0.7	5.2, 0.7	4.8, 0.7	4.6, 1.1	5.5, 0.9	5.5, 0.4	5.1, 0.7	5.3, 0.8	5.1, 0.9	5.2, 0.8	Post: $TD_{[Exp]} > TD_{[Con]}$*
Physical coordination [1–6]	4.3, 0.8	4.6, 0.8	4.2, 1.0	3.7, 1.4	3.3, 1.1	3.4, 1.7	5.0, 0.6	5.0, 1.1	4.8, 1.1	4.7, 0.9	4.6, 1.1	4.9, 0.9	Post: Exp > Con*
Body fat [1–6]	4.4, 1.5	4.2, 1.7	4.6, 1.7	3.8, 2.2	3.8, 2.0	3.9, 2.2	5.3, 1.0	5.6, 0.9	5.4, 1.0	5.3, 0.9	5.2, 1.0	5.2, 1.2	—
Sporting ability [1–6]	3.9, 1.1	4.1, 1.2	3.9, 1.2	3.1, 1.2	3.3, 2.0	3.4, 1.7	4.4, 1.0	4.7, 1.1	4.7, 1.2	4.7, 0.9	4.7, 1.0	4.9, 1.1	—
Physical self-concept [1–6]	4.4, 1.2	4.8, 1.2	4.4, 1.2	4.3, 1.1	3.9, 1.1	3.8, 1.5	5.0, 0.8	5.1, 0.9	5.0, 1.0	5.2, 0.9	5.1, 0.9	5.1, 0.8	—
Physical appearance [1–6]	4.0, 1.0	4.0, 1.2	4.1, 1.8	4.1, 1.0	4.2, 1.2	3.9, 1.3	4.3, 1.3	4.4, 1.4	4.2, 1.4	4.5, 0.8	4.7, 0.8	4.6, 1.0	—
Physical strength [1–6]	4.4, 1.0	4.5, 1.1	4.4, 0.9	4.3, 1.1	3.6, 1.2	3.7, 1.3	4.4, 1.0	4.6, 1.1	4.5, 1.1	4.4, 0.8	4.3, 0.8	4.5, 0.9	Post: Exp > Con*
Physical flexibility [1–6]	4.4, 0.9	4.4, 0.8	4.3, 1.0	4.2, 1.2	4.0, 1.4	3.7, 1.5	4.9, 0.7	5.1, 0.9	4.9, 1.0	5.0, 0.8	4.7, 1.1	4.9, 0.8	—
Physical fitness [1–6]	3.9, 1.0	4.0, 1.2	3.8, 1.3	3.2, 1.3	2.8, 1.5	3.0, 1.8	4.0, 1.1	4.3, 1.3	4.1, 1.2	4.4, 0.9	4.0, 1.2	4.2, 1.4	Post: Exp > Con*
Global self-esteem [1–8]	4.3, 0.8	4.4, 0.8	4.4, 1.0	4.4, 0.8	4.2, 0.9	4.4, 1.0	4.8, 0.8	4.9, 1.8	4.7, 1.2	4.7, 0.8	4.7, 1.1	4.8, 1.0	—

Note. DCD = developmental coordination disorder; $DCD_{[Exp]}$ = children with DCD who received fundamental movement skills training; $DCD_{[Con]}$ = children with DCD who performed regular physical education class; FMS = fundamental movement skills; MVPA = moderate to vigorous physical activity; TD = typical development; $TD_{[Exp]}$ = TD children who received FMS training; $TD_{[Con]}$ = TD children who performed regular physical education class.

*$p < .05$.

Table 5 Descriptive Statistics for Sleep Disturbance in All Groups at Baseline (Pre), Posttest (Post), and Follow-up (FU) Test, *M*, *SD*

	$DCD_{[Exp]}$			$DCD_{[Con]}$			$TD_{[Exp]}$			$TD_{[Con]}$			
Variable [score]	Pre	Post	FU	Pre	Post	FU	Pre	Post	FU	Pre	Post	FU	Significant difference
Bedtime resistance [6–18]	9.9, 2.9	9.5, 2.7	9.0, 2.7	9.3, 2.1	8.4, 1.8	8.5, 2.3	7.9, 2.0	8.6, 2.5	7.8, 1.9	9.0, 2.2	8.7, 2.5	8.4, 2.3	—
Sleep onset delay [1–3]	1.5, 0.7	1.9, 0.9	1.8, 0.8	1.3, 0.6	1.4, 0.6	1.4, 0.7	1.8, 0.9	1.4, 0.6	1.6, 0.8	1.6, 0.8	1.4, 0.7	1.7, 0.8	—
Sleep duration [3–9]	4.6, 1.4	4.6, 1.6	4.6, 1.3	4.8, 1.6	4.4, 1.3	4.9, 1.8	4.4, 1.4	4.2, 1.1	3.9, 1.3	4.6, 1.8	4.7, 1.7	4.9, 1.7	—
Sleep anxiety [4–12]	6.6, 2.1	5.7, 1.7	6.2, 2.0	6.1, 2.1	5.8, 1.3	6.0, 2.0	5.5, 1.8	5.6, 2.1	5.1, 1.6	5.3, 1.5	5.9, 1.9	5.4, 1.9	—
Night waking [3–9]	3.4, 0.9	3.7, 1.5	3.4, 0.7	3.4, 0.6	3.2, 0.4	3.4, 0.5	3.2, 0.6	3.2, 0.5	3.1, 0.2	3.4, 0.9	3.3, 0.7	3.3, 0.6	—
Parasomnias [7–21]	8.8, 2.3	9.1, 2.9	8.5, 1.4	8.1, 1.5	8.0, 1.3	8.0, 1.2	8.2, 1.3	8.7, 1.8	8.0, 1.1	8.3, 1.5	8.1, 1.4	8.3, 1.1	—
Sleep disordered breathing [3–9]	3.7, 1.1	4.0, 1.5	3.8, 1.2	3.7, 0.8	3.7, 0.8	3.8, 1.0	3.5, 0.6	3.7, 0.7	3.4, 0.7	3.2, 0.4	3.3, 0.4	3.3, 0.6	—
Daytime sleepiness [8–24]	13.7, 3.1	14.3, 3.4	13.3, 3.3	11.4, 3.3	11.5, 2.9	11.4, 2.4	14.2, 3.4	13.8, 3.2	12.4, 3.3	12.5, 2.4	12.8, 2.6	12.6, 3.2	—
Total sleep disturbance [33–99]	48.6, 6.6	49.6, 8.6	47.5, 6.9	44.6, 5.3	43.4, 5.5	44.5, 6.7	45.9, 6.4	46.2, 6.8	42.7, 5.5	45.3, 6.2	45.2, 4.9	45.2, 5.8	$DCD_{[Exp]}$ & $TD_{[Exp]}$: Post > FU*

Note. DCD = developmental coordination disorder; $DCD_{[Exp]}$ = children with DCD who received fundamental movement skills training; $DCD_{[Con]}$ = children with DCD who performed regular physical education class; FMS = fundamental movement skills; MVPA = moderate to vigorous physical activity; TD = typical development; $TD_{[Exp]}$ = TD children who received FMS training; $TD_{[Con]}$ = TD children who performed regular physical education class.

*$p < .05$.

children with TD, object-control skill proficiency was positively associated with sporting ability (r = .618), physical flexibility (r = .531), and physical fitness (r = .628) (all p < .05).

Discussion

To our knowledge, the current study is the first to deliver a school-based and task-oriented motor skill intervention (focusing on FMS) using an error-reduced learning strategy in children with DCD. This study explored the effects of FMS training on FMS proficiency, SPC, PA, and sleep behaviors in this group of children when compared with children with TD. Results indicated that FMS training effectively improved FMS (both locomotor and object control skills) proficiency of children with DCD and improved object control skills proficiency, in particular, of children with TD. SPC and sleep disturbance but not PA levels of children with DCD and TD were improved after receiving FMS training.

Consistent with previous findings (Willoughby & Polatajko, 1995), children with DCD showed poorer performance in both locomotor skills and object-controls skills than children with TD at baseline. As predicted, the performance of children with DCD improved in jumping and catching immediately after the intervention (i.e., at posttest), and the improvement in catching was still evident 6 weeks after the intervention (i.e., at follow-up). The findings indicate that FMS training underpinned by error-reduced learning effectively improved the movement patterns of FMS in children with DCD, and such benefits could be sustained for at least 6 weeks. Children with DCD exhibit deficits in their working memory (Alloway & Archibald, 2008). Error-reduced learning can avoid the involvement of working memory by minimizing errors during practice. Thus, this paradigm to training seems more effective for children with DCD when compared with children with TD in terms of object-control skills.

FMS training was equally effective in improving object-control skills (including kicking and throwing) of children with DCD and of children with TD. It has been noted that object control skills in particular, are more difficult to train (Logan et al., 2012), presumably due to its greater complexity relative to locomotor skills. The findings of this current study show that the error-reduced learning may be effective in managing such difficulty in object control skills training. This may have significant implications for educators who are responsible for effective motor training programs for children with and without motor impairments.

Surprisingly, children with TD who received FMS training were found to fall behind in terms of locomotor skills compared with their peers in the control group. This suggests a reverse effect of FMS training occurred in the locomotor skills of children with TD. The “challenge point” framework states that an optimal level of task difficulty must first be reached for learning to occur and that learning will be compromised when too little challenge is provided (Guadagnoli & Lee, 2004). In the current study, the task difficulty for FMS in each session for children with TD was identical to that for children with DCD (Table 1). It has been found that primary school children in Hong Kong display good locomotor skills proficiency, but not object-control skills (Pang & Fong, 2009). Thus, the training tasks for locomotor skills may have been too easy for children with TD whereas there is room for them to improve their object-control skills in the training program. As such, the present findings indicate the importance of varying difficulty levels of training skills (particularly in locomotor skills) for children with and without motor impairments in future interventions.

The present study provides evidence on the role of FMS training in improving SPC. Children who received FMS training viewed themselves as having better physical coordination, physical strength, and physical fitness than children in the control groups immediately after the intervention. The finding indicates that both children with DCD and children with TD have insight into specific areas of their improvements in physical competence. The FMS training in the current study was designed to prevent errors during practice by increasing task difficulty progressively over time and to enable all the children, regardless of motor impairments, to experience a sense of mastery and success. As such, the children could develop good self-perceptions of their competence. The improvement of self-perceived physical coordination seems more essential to children with DCD, not only because of poorer physical coordination of children with DCD than children with TD before the intervention, but also because self-perceptions of physical coordination play a significant role in developing FMS in children with DCD (Yu et al., 2015).

Data from the correlational analysis revealed that children with DCD who displayed improved FMS proficiency are more likely to view themselves as having improved physical competence. Interestingly, various positive and moderate relationships were observed between SPC (i.e., physical coordination, sporting ability, physical self-concept, and physical strength) and locomotor skills immediately after the intervention in children with DCD, even though proficiency in both locomotor skills and object-control skills improved after the intervention. Most of the SPC in the earlier mentioned relationships are those variables in which children with DCD showed significantly lower scores than their TD peers. The findings show that children with DCD are more likely to be aware of their performance in locomotor skills than in object-control skills. A possible reason for this is that locomotor skills are the primary parts of the daily movements of local children (Pang & Fong, 2009). Our results showed a moderate and positive correlation of object-control skills with physical appearance in children with DCD 6 weeks after the intervention. Object-control skills were also positively related to various SPC (i.e., sporting ability, physical flexibility, and physical fitness) in children with TD in the current study. These findings highlight the significance of improved proficiency of both locomotor skills and object-control skills on SPC in children with and without impairments.

In previous intervention studies (Hillier, McIntyre, & Plummer, 2010; Peens et al., 2008), the effectiveness of motor skills training on SPC of children with DCD was inconsistent. Based on the findings of the current study, we suggest that FMS training underpinned by error-reduced learning appears to be a useful treatment program for children with DCD because it not only benefits the motor proficiency of children with DCD, but also allows them to develop positive feelings about their physical competence. Importantly, a "positive loop" between SPC and actual motor competence is believed to exist (Harter, 1987); that is, children who have positive perceptions of their competence are more likely to attempt and practice motor skills and, subsequently, maintain engagement in a specific activity. Therefore, we suggest that the FMS training program developed in the current study may be a feasible plan for improving motor proficiency in children with DCD in an effective and sustainable way, and this is of great value for those rehabilitation professionals and educators working with this group of children.

According to the ICF-CY model, the intervention on motor performance may influence activity and participation of children. The present study demonstrated that FMS training benefits the sleep quality of children with DCD. Children with DCD who received FMS training exhibited less sleep disturbance 6 weeks after the intervention. This study is the first to examine and verify the effectiveness of FMS training on reducing sleep disturbance of children with DCD, and this finding warrants future research attention. When considering the poorer sleep quality (bedtime resistance and sleep anxiety) of children with DCD than children with TD before the intervention, more attention should be paid to sleep behaviors, its association with motor proficiency, and the mechanism behind this relationship in children with DCD in future research.

Although, as discussed earlier, FMS training in the current study was effective in improving FMS proficiency, SPC, and sleep disturbance in children with DCD, the training program was not more effective in promoting their PA levels when compared with conventional PE classes. We only found that locomotor skill proficiency was positively associated with PA volume and the percentage of time spent in MVPA in children with TD, consistent with previous findings (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). However, no such association was found in children with DCD. This result seems inconsistent with the finding in a previous study reporting that children with DCD had increased PA levels after attending motor skills training based on their parents' report (Iversen et al., 2005). Despite the possible existence of recall bias in assessing PA in that study, we believe it is necessary to discuss our findings through comparison with previous work to facilitate the development of future intervention strategies. In the study by Iversen et al. (2005), two experimental groups of children with DCD undertaking different intervention strategies were involved. Group I had received a high-dosage (daily practice over 1 school year), targeted motor skills approach (e.g., bicycling, swimming, FMS) with parental involvement, whereas a low-dosage (weekly practice 1 school year), basic motor skills (i.e., FMS) approach with limited parental involvement was applied in Group II. They found the improvement of PA in Group I in comparison with Group II highlighted the importance of intensity of training, environment for practice, and parental inclusion for PA promotion. Based on the work by Iversen et al. (2005), a short-term FMS training in the current study seems not intensive enough to promote PA in children with DCD. In future studies, an optimal intensity of FMS training in promoting PA in this group of children should be explored. In addition, we suspect that more practice of FMS in the daily living environment (e.g., jump over an obstacle, run up and down the stairs) with parents' support may help transfer the increase of motor proficiency into promoting PA participation in children with DCD. This notion, however, needs to be examined in the future.

According to the ICF-CY model, the relationships between body function, activity, and participation vary depending on social context. Capio et al. (2015a) found that FMS training effectively increases PA of children with disabilities on weekend days but not on weekdays. They argued that the weekend activities of children are possibly less structured and more dependent on movement patterns compared with weekday activities. Unfortunately, the current study failed to examine the effects of FMS training on weekend PA levels. In addition, although using accelerometers has many advantages over using self-reported measures to assess PA levels, accelerometers are limited to measuring the intensity of activity and cannot provide information on activity type or context of PA (Pate, O'Neill, & Mitchell, 2010). Given the importance of engaging in PA for children with DCD, further research is needed to comprehensively explore the effects of FMS training in promoting PA in this group of children.

In summary, the findings of the current study support the efficacy of a short-term and school-based FMS training program in improving FMS proficiency and SPC and in reducing sleep disturbance in children with and without DCD. We suggest that FMS training with an error-reduced learning strategy provides a potential avenue for rehabilitation professionals and educators working with children with DCD in the field. However, it should be noted that all the significant improvements showed a trivial to small effect size (ranging between .06 and .20). When considering the importance of motor proficiency, self-perceptions of physical abilities, and participation in activities of daily living for children with DCD, the effectiveness of FMS training requires further attention.

Limitations

First, the study employs a quasi-experimental design, and the group allocations were not fully randomized for logistical reasons. Second, the sample size was small and unequal. These limitations on sampling may underestimate the effects of FMS training. Moreover, the proportion of girls (40.9%) in the $DCD_{[Exp]}$ group was high in the current study when compared with the low ratio of girls to boys (1:2–1:7) with regard to DCD prevalence (Kadesjö & Gillberg, 1999). Therefore, the results may not be generalizable due to gender imbalance. Third, the sample of children with DCD in the current study may lack of homogeneity, due to the use of 15th instead of 5th percentile of MABC-2 test score to identify their motor impairments. In addition, the effects of FMS intervention were not assessed with taking DCD severity into account because of insufficient sample size. Fourth, PA levels on weekend days were not available for data analysis due to the poor compliance of participants in wearing accelerometers. Finally, a proxy-report questionnaire was used to measure sleep disturbance, and there is a bias of recall memory. Objectively measured sleep disturbance, therefore, warrants future investigations.

Conclusions

FMS training effectively improves both locomotor skills (jumping) and object-control skills (catching and kicking) of children with DCD, and their improvements in object-control skills (catching and throwing) were sustained for at least 6 weeks. FMS training also effectively improves SPC of children with DCD in terms of physical coordination, physical strength, and physical fitness immediately after the training. Children with DCD experience less sleep disturbance 6 weeks after FMS training. We suggest that short-term FMS training underpinned by error-reduced learning appears to be an effective training program in improving FMS proficiency and SPC, and reducing sleep disturbances for both children with and without DCD. Future studies with a larger sample and a true randomized controlled trial design are warranted to confirm these findings.

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