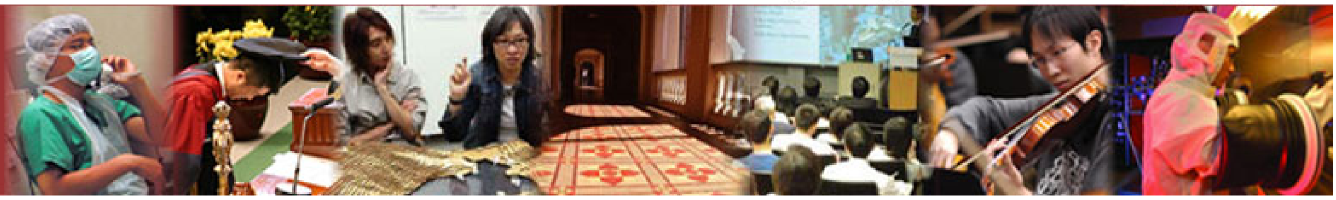

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Taekwondo training improves sensory organization and balance control in children with developmental coordination disorder: A randomized controlled trial

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Abstract

Children with developmental coordination disorder (DCD) have poorer postural control and are more susceptible to falls and injuries than their healthy counterparts. Sports training may improve sensory organization and balance ability in this population. This study aimed to evaluate the effects of three months of taekwondo (TKD) training on the sensory organization and standing balance of children with DCD. It is a randomized controlled trial. Forty-four children with DCD (mean age: 7.6±1.3 years) and 18 typically developing children (mean age: 7.2±1.0 years) participated in the study. Twenty-one children with DCD were randomly selected to undergo daily TKD training for three months (one hour per day). Twenty-three children with DCD and 18 typically developing children received no training as controls. Sensory organization and standing balance were evaluated using a sensory organization test (SOT) and unilateral stance test (UST), respectively. Repeated measures MANCOVA showed a significant group by time interaction effect. Post hoc analysis demonstrated that improvements in the vestibular ratio (p=0.003) and UST sway velocity (p=0.007) were significantly greater in the DCD-TKD group than in the DCD-control group. There was no significant difference in the average vestibular ratio or UST sway velocity between the DCD-TKD and normal-control group after three months of TKD training (p>0.05). No change was found in the somatosensory ratio after TKD training (p>0.05). Significant improvements in visual ratios, vestibular ratios, SOT composite scores and UST sway velocities were also observed in the DCD-TKD group after training ($p \leq 0.01$). Three months of daily TKD training can improve sensory organization and standing balance for children with DCD. Clinicians can suggest TKD as a therapeutic leisure activity for this population.

Keywords: sport, postural control, sensory inputs, clumsy children

1. Introduction

Approximately six percent of school-aged children are known to have developmental coordination disorder (DCD). These children experience difficulty in daily activities due to their marked motor impairments including poor postural control (APA, 2000). Previous studies have reported that 73% to 87% of children with DCD actually have balance problems (Macnab, Miller, & Polatajko, 2001). The ability to maintain postural stability in children with DCD is an important area that needs to be addressed because any impairment in postural control may limit the child's activity participation (Fong et al., 2011b; Fong, Lee, & Pang, 2011a; Smyth & Anderson, 2001), increase their risk of falling, hinder motor skills development (Grove & Lazarus, 2007) and have a negative impact on their psychosocial functioning (Cantell, Smyth, & Ahonen, 1994; Skinner & Piek, 2001).

The control of posture involves efficient use of information from the somatosensory, visual and vestibular systems (Nashner, 1997). Children with DCD have below-normal balance ability together with wide-spread impairment in their sensory organization (Fong et al., 2011a; Inder & Sullivan, 2005). Their ability to rely on vestibular input to maintain standing balance is worse than that of children with normal motor development (Grove & Lazarus, 2007). Without proper intervention, the balance and motor deficits that arise from DCD may persist into adolescence and even adulthood (Fitzpatrick & Warkinson, 2003; Losse et al., 1991). Early intervention to enhance motor and balance performance is thus very important.

Sports training is often a viable and enjoyable way of improving the balance of children with DCD (Hung & Pang, 2010; Mercer, Sahrmann, Diggles-Buckles, Abrams, & Norton, 1997). Indeed, a survey shows that physiotherapists often refer children with motor dysfunctions to participate in sports activities (Westcott, Murray, & Pence, 1998). Taekwondo (TKD) is a popular sport among children and adolescents (Park, Park, & Gerrard, 1989). It is renowned for its swift kicks and fast action. Practitioners have ample opportunity to practise single leg standing while maintaining body balance (Pieter, 2009). Previous studies in our own laboratory have demonstrated that participation in TKD can enhance postural control and sensory organization in typically developing adolescents. TKD practitioners rely primarily on visual and vestibular inputs to maintain standing balance (Fong, Fu, & Ng, 2011c; Fong & Ng, 2010; Leong, Fu, Ng, & Tsang, 2011). The potential benefits of TKD may exactly address the balance difficulties and sensory organization deficits experienced by children with DCD. However, the training effect of TKD has not been investigated formally with a DCD population.

This randomized controlled study aimed (1) to investigate the effect of short-term (three months) intensive TKD training on the sensory organization and balance performance of children with DCD, and (2) to identify the developmental status of balance and sensory organization in children with DCD, both with and without TKD training, as compared to children with normal motor development.

2. Methods

2.1. Study design

This was a single-blinded, stratified, randomized and controlled trial. The outcome assessors were blinded to the group allocation. Since the participants were not blinded to group assignment, they were instructed not to inform the assessors about their group assignments to avoid possible bias during measurement.

2.2. Participants

According to a meta-analysis by Pless & Carlsson (2000), the minimal effect size for gross motor training (group training) in improving the motor proficiency, including balance ability, of persons with DCD is 0.54. Therefore, a sample of 29 participants was necessary to achieve a statistical power of 0.8 in pretest and post-test measurements of two DCD groups with the alpha level set at 0.05. Anticipating a possible dropout of 30% (Hiller, McIntyre, & Plummer, 2010), 38 children were needed (i.e., 19 per group).

Participants with DCD were recruited from local child assessment centres (CACs) and hospitals. Inclusion criteria were: (1) a formal diagnosis of DCD according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA, 2000); (2) aged between six and nine years; (3) study in a regular education framework; and (4) no intellectual impairment. Exclusion criteria were: (1) a formal diagnosis of emotional, neurological, or other movement disorders; or (2) a significant congenital, musculoskeletal or cardiopulmonary condition that might influence balance performance; or (3) were receiving physical or occupational therapy training; or (4) demonstrated excessive disruptive behavior; or (5) could not follow instructions thoroughly (Fig. 1). Children with normal motor development were recruited from the community by convenience sampling to form a normal control group using the same inclusion and exclusion criteria except that they did not have any history of DCD. Each child in the normal-control group was screened by an experienced pediatric physical therapist using the Movement Assessment Battery for Children-2 (Movement ABC-2). Children with a Movement ABC-2 total percentile score at or below the 15^{th} percentile (i.e., those at risk of significant movement difficulty) were excluded (Henderson, Sugden, & Barnett, 2007).

A no-training DCD-control group was also included to account for the effect of maturation and to track whether the balance deficits of those with DCD might recover spontaneously over time. The normal children were included as another control group to determine whether or not short-term TKD training can improve the balance ability of children with DCD to normal standards.

Ethical approval was obtained from the Human Subjects Ethics Review Subcommittee of the Hong Kong Polytechnic University. The study was explained to each participant and their guardian, and written informed consent was obtained. Data collection was performed by pediatric physical therapists. All procedures were conducted in accordance with the Declaration of Helsinki.

2.3. Randomization

The eligible participants with DCD were stratified by gender and then randomly assigned to either the DCD-TKD training group or the DCD-control group. This ensured an approximately equal number of boys and girls in each group. The randomization procedure was done by drawing lots and was completed by a person independent of the study. Twenty-one and twenty-three children with DCD were assigned to the DCD-TKD group and DCD-control group, respectively (Fig. 1). Eighteen typically developing children were included in the normal-control group without randomization.

2.4. Intervention

The children in the DCD-TKD training group attended a weekly one-hour session of TKD training held at the Hong Kong Polytechnic University for twelve consecutive weeks. The TKD training protocol is outlined in Table 1. This protocol was modified from a typical TKD syllabus for beginners (Park et al., 1989) by an experienced physical therapist and a skilled taekwondo practitioner to suit the motor ability of the participants. The TKD training sessions were conducted by a World Taekwondo Federation 4^{th} dan black belt qualified as a chief instructor and a 2^{nd} dan black belt qualified as an assistant instructor.

In addition, each participant was given TKD home exercises to reinforce what had been learned at each training session and to increase the exercise frequency. The home exercises were same as those practiced during face-to-face TKD training sessions. The children were instructed to perform these TKD exercises daily (excluding the TKD class days) throughout the three month study period. Their guardians were provided with clear written instructions and a log book, and were asked to coach or assist their children in performing the TKD home exercises. The home exercise programme was designed to take approximately an hour to complete. The log books were designed to be completed daily by the guardians. To ensure all participants complied with the home exercises, the TKD instructors checked the participants' daily log books at each training session and the guardians were required to submit their signed log books to the researchers at the post-intervention assessment. The DCD-control and normal-control groups received no training within the study period.

2.5. Outcome measurements

All participants were assessed one month before the start of the TKD intervention and again within two weeks after it ended by an assessor blinded to the group allocation. Each participant, regardless of group assignment, underwent the following pre- and post-intervention assessments.

2.5.1. Sensory organization of balance control

Sensory organization was evaluated using the sensory organization test (SOT) with a computerized dynamic posturography (CDP) machine (Smart Equitest, NeuroCom International Inc., Clackamas OR, USA). The SOT is commonly used to evaluate the use of somatosensory, visual and vestibular inputs and the ability to filter out inappropriate sensory information in maintaining balance in bipedal stance (Nashner, 1997; NeuroCom, 2008). The results have been found to be reliable and valid with young subjects (Di Fabio & Foundriat, 1996).

The participants stood with bare foot on the platform of the CDP machine for testing and wore a security harness to prevent falls. They were instructed to stand quietly with both arms resting by the sides of the trunk and eyes looking forward at a distant visual target. They were exposed to six different combinations of visual and support surface perturbations in sequence according to the protocol provided by NeuroCom Inc. In conditions 1 to 3 the participants stood on a fixed platform with their eyes open (condition 1), eyes closed (condition 2) and eyes open in a sway-referenced visual surround (condition 3). In conditions 4 to 6 the participants stood on a sway-referenced platform with their eyes open (condition 4), eyes closed (condition 5) and eyes open in a sway-referenced visual surround (condition 6). The term 'sway-referenced' is used to describe the tilting of the support surface and/or the visual surround about an axis co-linear with the ankle joints to closely follow the anterior-posterior sway of the participant's centre of gravity (Nashner, 1997; NeuroCom, 2008). After a familiarization trial, each participant was tested three times in each condition at each evaluation. They were instructed to ignore any support surface or visual surround motion and remain upright as steady as possible for 20 seconds in each trial. No feedback was given to the participants during the testing (NeuroCom, 2008).

The CDP machine captured the trajectory of the participant's center of pressure (COP), which was then used to generate an equilibrium score (ES). The score was calculated by subtracting each participant's peak antero-posterior (AP) sway angle from the theoretical limit of AP stability (assumed to be 12.5°) and dividing the difference by the limit. So an ES of 100 represented no sway in bipedal standing whereas a score of zero indicated sway exceeding the stability limit, which would normally result in a fall (Nashner, 1997; NeuroCom, 2008).

The three ES scores in each testing condition were averaged, and these average scores were used to calculate a somatosensory ratio (the mean ES of condition 2 divided by the mean ES of condition 1), a visual ratio (the mean ES of condition 4 divided by the mean ES of condition 1) and a vestibular ratio (the mean ES of condition 5 divided by the mean ES of condition 1) (NeuroCom, 2008). These three sensory ratios were then used to identify the contribution of each sensory system—somatosensory, visual and vestibular—to balance control. A sensory ratio close to 1 reflected superior ability in relying on that particular sensory input for balance (Nashner, 1997). A composite ES was also generated by the NeuroCom software taking into account the ESs in all the six testing conditions (NeuroCom, 2008). The composite ES and the three sensory ratios were used for analysis.

2.5.2. Single leg standing balance

Single leg standing balance was measured in a unilateral stance test (UST) with the same CDP machine. Participants stood barefoot on their non-dominant leg for ten seconds. (The dominant leg was defined as the one each participant reported using to kick a ball.) (Fong et al., 2011c). The non-dominant leg was tested because it is usually the supporting leg during TKD. The standardized testing posture was arms by the side of trunk, eyes looking forward at a distant visual target and the hip of the non-supporting leg flexed at 45° so as to resemble the starting position of a front kick in TKD. The sway velocity of the center of pressure (COP) was recorded by the machine (NeuroCom, 2008). Three trials were performed with a ten-second rest in between. The mean COP sway velocity across the three trials was obtained and used for analysis. Previous study has shown that the test-retest reliability of the UST is good with an intraclass correlation coefficient of 0.77 (Fong et al. 2011c).

2.6. Statistical analysis

One-way analysis of variance (ANOVA) and chi-square tests were conducted to compare the groups in terms of age, weight, height and gender distribution. To test the overall effect of TKD training and to reduce the probability of type I error due to multiple comparisons, two-way repeated measures multivariate analysis of covariance (MANCOVA) was conducted incorporating all the outcome measures (somatosensory ratio, visual ratio, and vestibular ratio, SOT composite score, UST COP sway velocity). The within-subject factor was time and the between-subject factor was group. The intention-to-treat principle was employed. Baseline (pretest) somatosensory ratio, visual ratio, vestibular ratio, SOT composite score, and UST COP sway velocity were entered as covariates if there was any significant baseline between-group difference in these measures.

If the MANCOVA demonstrated a significant effect overall, follow-up analyses were performed using one-way analysis of covariance (ANCOVA) and post-hoc pairwise comparisons. In addition, pairwise t-tests were used to investigate whether there was any within-group difference within the two assessment intervals. All of the statistical analyses were performed using SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA). The significance level was set at 0.05 (two-tailed) and corrected using an appropriate Bonferroni adjustment for the univariate tests in order to maintain the overall type one error at 5% (i.e., alpha=0.01 for comparisons of the five outcomes among groups).

3. Results

Figure 1 shows that 62 children with DCD (n=44) and without DCD (n=18) who met the inclusion criteria participated in the study. Twenty three of them (37%) dropped out—five from the DCD-TKD group (i.e., 76.2% completed the TKD intervention), ten from the DCD-control group, and eight from the normal-control group. The self-reported reasons for drop-out are listed in Figure 1. The average attendance at the face-to-face training sessions for those who completed the TKD intervention was 90.9%. No adverse events were reported during the TKD training. The self-reported TKD home exercise compliance rate was 95.2%.

3.1. Comparison of baseline characteristics

The demographics of the three groups are outlined in Table 2. There was no significant difference in boy to girl ratio or average BMI, height, age or weight among the three groups (p>0.05). Significant differences were found in the pretest measurements of vestibular ratio (p=0.012) and UST COP sway velocity (p=0.003) among the three groups (Table 3). The baseline vestibular ratio and the UST COP sway velocity were therefore treated as covariates in the subsequent multivariate and univariate analyses.

3.2. Changes in the somatosensory ratio

No significant time by group interaction was found involving the somatosensory ratio (p=0.332). There was no significant pretest or post-test difference (p>0.01) among the groups, which indicates that the three groups were comparable in terms of somatosensory ratio before and after three months, regardless of TKD training. The children with normal development demonstrated some improvement in their somatosensory ratios over time (p=0.048) (Table 3).

3.3. Changes in the visual ratio

For the visual ratio, a significant time by group interaction ($p<0.001$) was found. Paired t-tests revealed that only children with DCD who received TKD training had significant improvement (increased by 25.9%, $p=0.001$) after three months. No improvement was found in the two control groups ($p>0.05$). Between-group comparisons demonstrated that the differences among the three groups were not statistically significant after the intervention ($p>0.01$) (Table 3).

3.4. Changes in the vestibular ratio

Repeated measures MANCOVA revealed a significant time by group interaction effect ($p<0.001$) in terms of the vestibular ratio. Children with DCD showed a significant improvement (71.9%, $p<0.001$) in vestibular ratio after three months of TKD training. No significant improvement was found in either control group over time ($p>0.05$). The average vestibular ratio of the DCD-TKD group was significantly lower (37.3%, $p=0.012$) than that of the normal-control group before receiving TKD training. However, after three months of TKD training the average vestibular ratio of the DCD-TKD group was 61.8% higher than that of the DCD-control group and comparable to that of the normal-control group ($p>0.01$) (Table 3).

3.5. Changes in the SOT composite score

There was a significant time by group interaction ($p=0.026$) in the SOT composite score. DCD-TKD group demonstrated the greatest improvement over time (18.5%, $p=0.001$), followed by the DCD-control group (5.8%, $p=0.023$) (Table 3). Within-group differences were not significant ($p>0.05$) in the normal-control group. However, there was no difference ($p>0.01$) in the composite scores among the three groups pretest or post-test.

3.6. Changes in the UST COP sway velocity

Repeated measures MANCOVA also showed a significant time by group interaction ($p=0.001$) in the UST COP sway velocity. Post hoc univariate analyses revealed that the DCD-TKD training group had significantly greater improvement in average UST COP sway velocity than the two control groups. Children with DCD swayed 30.5% slower when standing on one leg after three months of TKD training ($p=0.004$) and their UST COP sway velocity became comparable to that of their typically developing peers ($p>0.05$). The DCD-control group (without TKD training) did not improve over time ($p>0.05$) and their post-test UST COP sway velocity was 121.6% higher than that of the normal-control group ($p=0.001$) and 71.5% higher than that of the DCD-TKD ($p=0.007$) group (Table 3).

4. Discussion

4.1. Development of postural control in children with DCD

Our findings reveal that before the TKD intervention, children with DCD (six to nine years old) demonstrated faster COP sway in single leg standing and lower vestibular ratio in the SOT than typically developing children. The somatosensory ratios, visual ratios and SOT composite scores were similar, however (Table 3). These findings partially agree with those of previous researchers (Fong et al., 2011a; Grove & Lazarus, 2007; Inder & Sullivan, 2005). For example, Grove & Lazarus (2007) evaluated 16 children with DCD and 14 children with normal motor development using the Equitest SOT and found that the ability to use vestibular feedback for balance was impaired in children with DCD (six to twelve years old), somatosensory and visual inputs were thus weighted more heavily in postural control. Recently, a group led by Fong has reported more generalized deficits in the sensory systems for postural control in a DCD population (Fong et al., 2011a). They found that the SOT composite score and all the sensory ratios were lower in the DCD group (n=81, six to twelve years old) when compared to a control group (n=67). These inconsistent findings may be due to the heterogeneity of DCD populations and the different gender mixes among the studies.

A group led by Cherng used the modified Clinical Test of Sensory Interaction and Balance (CTSIB) and found that children with DCD (four to six years old) could use information from the three sensory systems to maintain balance as efficiently as typically developing children. They concluded that the poor standing balance observed in children with DCD was likely due to a deficit in sensory organization rather than compromised effectiveness in individual sensory systems (Cherng, Hsu, Chen, & Chen, 2007). Their distinct findings could be explained by the use of younger children and different testing instruments.

Children with DCD certainly demonstrate deficits in standing balance and sensory organization, though the extent of involvement of the three sensory systems remains unclear. Further study is needed to take all the possible confounding factors (e.g., gender, age) into account and used standardized instruments in order to properly confirm the extent of sensory deficits in this population.

4.2. Sensory organization and postural control following TKD training

This has been the first study to investigate the effect of short-term, intensive TKD training on sensory organization and balance control in children with DCD. The TKD exercise program was achievable for most of the participants, and improvements in postural stability and the sensory organization of balance control were observed in those participants who complied with the TKD regime.

Children with DCD, with or without TKD training, demonstrated ability in relying on somatosensory information to maintain balance similar to that of normal adolescent TKD practitioners and non-practitioners (Fong et al., 2011c). Their somatosensory ratio was comparable to that of normal children at both pretest and post-test (Table 3). This could be attributed to the fact that the somatosensory function matures at the age of three or four (Cumberworth, Patel, Rogers, & Kenyon, 2007; Hirabayashi & Iwasaki, 1995; Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006). These children (six to nine years old) could already have had mature somatosensory functioning. TKD training may not have been able to improve it further

(Fong et al. 2011c). This is contrary to some reports that proprioception can be further improved in mature adults by sports training (Lephart, Giraldo, Borsa, & Fu, 1996; Tsang & Hui-Chan, 2003). One possible explanation might be that the somatosensory ratio studied here compared SOT in condition 2 to condition 1, quantifying the extent of stability loss when the participant closed their eyes in standing (Nashner, 1997). This may not be a valid reflection of the DCD-TKD participants' ability to use somatosensory information for balance, as the TKD intervention did not involve balancing with the eyes closed. The intervention was also relatively short. Three months of TKD training may not be enough to significantly improve the participants' ability to rely on somatosensory input for balance. Further study might fruitfully measure proprioception directly and explore the optimal duration of TKD training in order to improve proprioception in children with DCD.

Although the visual ratio was not significantly different among the three groups at post-test, TKD training significantly facilitates the development of visual function and organization in children with DCD. The visual ratio of the DCD-TKD group was 21.6% lower than that of the normal-control group before TKD training. After training, their average visual ratio was only 2.7% lower (Table 3). One may question whether this improvement was due to the training or simply to physiological maturation, as visual function does not fully mature until 15 or 16 years old (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). The DCD-control group, however, did not improve over time, which indicates that the TKD training had a differential effect.

Similar to soccer training, TKD involves the control of posture while kicking. The dual task demands on children who have to use vision to help maintain posture is considerable (Smyth & Anderson, 2001). Training may thus strengthen the ability to use visual input to maintain balance. Indeed, previous studies have found that TKD experts have greater visual field dependence than other physically active subjects (Christelle & Jacques, 2005). The absence of a significant difference among the three groups at post-test might be due to inadequate training duration. Further study should explore the optimal training duration in order to improve visual function and organization in children with DCD.

We found that children with DCD who received the TKD training achieved less body sway than those without training when they had to rely more on vestibular input to maintain standing balance. Of particular interest is that their vestibular ratio improved significantly (71.9%) and achieved the standard of typically developing children after TKD training, while the DCD-control participants (without TKD training) did not improve at all (Table 3). These findings suggest that TKD was very effective in improving the use of vestibular information for balance control in children with DCD. This is in line with previous findings that TKD training might enhance the vestibular system for maintaining postural equilibrium as reflected by quicker stabilization after landing from an unexpected drop (Leong et al., 2011).

So what contributed to the significant improvement in vestibular function in the DCD-TKD participants? A clear answer could have clinical applications. Analyzing the TKD techniques may provide some insights. The TKD protocol (Table 1) covered many movements that are actually similar to the vestibular exercises (e.g., spinning, jumping) commonly used in sensory integration (SI) therapy. SI therapy is known to be effective in remediating sensory deficits and enhancing motor skill development in children with DCD (Ayres, 1979; Cermak & Larkin, 2002; Sugden, 2007). TKD techniques such as the roundhouse kick, side kick and back kick may similarly stimulate sensory and vestibular functions, as they involve quick spinning (head and trunk rotation in unstable body positions) and vertical movements (Hansson, 2007). During TKD training these kicks were practiced repeatedly (Table 1), which presumably stimulated the vestibular system and developed single leg standing balance simultaneously in these children with DCD.

Unilateral stance stability is crucial for executing TKD high kicks (Pieter, 2009) and is essential for many daily activities such as donning pants, climbing stairs and even walking (NeuroCom, 2008; Stout, 2006). Three months of TKD training significantly improved the single leg standing balance of these children with DCD, bringing their balance performance up to the normal level. Without TKD training, unilateral stance stability did not improve over time and remained inferior to that of typically developing children (Table 3). Relying on maturation alone may not be able to improve single leg standing balance sufficiently in children with DCD. Sports training is thus vital (Smyth & Anderson, 2001).

Previous studies have proposed some explanations to clarify the above phenomenon (Del Percio et al., 2009; Perrin, Schneider, Deviterne, Perrot, & Constantinescu, 1998; Violan, Small, Zetaruk, & Micheli, 1997). Del Percio has suggested that frequent kicking practice with a mobile visuo-spatial target helps karate (a martial sport similar to TKD) athletes to cope with highly demanding visual-somatosensory-vestibular integration (Del Percio et al., 2009). Cerebral mechanisms for integrating somatosensory, visual and vestibular inputs might become more effective with prolonged training and result in less body sway in standing. Furthermore, Perrin has proposed that athletes in combat sports improve adaptive postural control with the skills acquired in training (Perrin et al., 1998). TKD practitioners might develop better postural adjustment strategies and body alignment during kicking and blocking, which would all improve body balance on one leg (Violan et al., 1997).

We incorporated static bipedal standing balance exercises (e.g., punching and blocking in horseback riding stance) in the TKD intervention because it is the foundation of unilateral stance stability. Thus we also examined balance ability in bipedal stance. The results reveal that both the DCD-TKD and DCD-control groups improved in bipedal standing balance over time, and the SOT composite scores were similar among the three groups at post-test (Table 3). This indicates that effect of maturation in children with DCD may be more profound than the effect of TKD training. Moreover, testing static balance in bipedal stance may not be challenging enough to expose the balance difficulties of children with DCD (Grove & Lazarus, 2007).

4.3. Limitations and future research directions

First, the total attrition rate in this study was quite high. The greatest attrition was in the two control groups, and the major reason was ‘lost to follow up’ or ‘unable to commit the time’. The children in the control groups did not receive any intervention, which may have disappointed the children and parents. They might not have been motivated to be assessed again at post-test. Future studies might better adopt a crossover design with an adequate washout period (Portney & Watkins, 2009). Second, although the TKD protocol was effective for improving certain balance processes, it is possible that longer intervention might be optimal for improving the sensory organization ability of children with DCD. Moreover, a follow-up assessment may be warranted to explore whether the balance ability gained can be retained and to define the washout period stated above. Finally, the relationships between balance measurements and fall risk or activity participation are not yet clear. Further study is required to address the clinical importance of these positive changes.

5. Conclusion

TKD training can remedy unilateral standing balance and vestibular function impairments in children with DCD. Their balance performance can reach normal standards after only three months of daily TKD exercise. Clinicians can therefore suggest TKD as a therapeutic leisure activity for children with DCD.

Declaration of conflicting interests

The authors declare that they have no conflicts of interest with respect to the authorship or publication of this article. No funding was provided for the preparation of the paper.

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Table

Table 1. Three-month taekwondo training protocol for the TKD-DCD group (Park et al., 1989)

Exercise or technique	**Frequency**	**Intensity**	**Duration**	**Type of activity and postural control requirements**
Warm up		Mild sweating	5 minutes	Jogging. Dynamic balance.
Stretching		Mild tension of muscles	5–10 minutes	Static stretch of all large muscle groups.
Punching and blocking in horseback riding stance: • Body punch • Rising block[a] • Outside block • Inside block • Down block[b]	TKD class: once per week Self practice (documented by logbook): daily (excluding the TKD class days)	20 repetitions for each technique. Performed with alternate upper limbs.	10–15minutes	Lower limb static and upper limb dynamic muscle contractions. Maintain static and dynamic balance in bipedal stance.
Break			5 minutes	

Kicking in fighting stance: • Front kick • Round house kick • Side kick[a] • Back kick[b] (With or without a kick pad)	40 repetitions for each technique. Performed with alternate lower limbs.	20–30 minutes	Dynamic coordinated muscle contractions in the upper limbs, lower limbs and trunk. Maintain dynamic balance in unilateral stance and during turning/ pivoting on one foot. Progressed by increasing the speed of movements.
Cool-down and stretching		10 minutes	Jogging and static stretch of large muscle groups. Dynamic balance.

[a] Techniques practiced from the 2nd week onward.

[b] Techniques practiced from the 4th week onward.

Table 2. Participant characteristics at baseline

	DCD-TKD group (n=21)	DCD-control group (n=23)	Normal-control group (n=18)	*p* value
Age, years	7.7±1.3	7.4±1.2	7.2±1.0	0.411
Gender (Male/female), n	17/4	18/5	14/4	0.965
Height, cm	127.4±9.9	123.2±11.2	122.7±10.1	0.294
Body weight, kg	28.1±9.2	26.7±10.1	27.3±8.4	0.892
BMI, kg/m^2	16.8±3.2	17.0±3.2	17.5±2.7	0.774
Co-morbidity				
Attention deficit hyperactivity disorder	3	4	0	
Attention deficit disorder	3	4	0	
Dyslexia	4	2	0	
Asperger syndrome	2	3	0	
Autism spectrum disorders	1	0	0	

Note. Values are mean ± SD.

Table 3. Comparison of outcome measurements among the three groups (pre- and post-TKD training) and within individual groups

Measurements	DCD-TKD group (n=21)		DCD-control group (n=23)		Normal-control group (n=18)		*p* value		
	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test	Pretest (Group effect)	Post-test (Group effect)	Group x time effect
SOT									
Somatosensory ratio	0.93± 0.07	0.91± 0.13	0.91± 0.09	0.92± 0.07	0.96± 0.04	0.97± 0.04[d]	0.074	0.503	0.332
Visual ratio	0.58± 0.19	0.73± 0.19[d]	0.57± 0.24	0.57± 0.23	0.74± 0.15	0.75± 0.16	0.019	0.012	<0.001[e]
Vestibular ratio	0.32± 0.16	0.55± 0.23[a,d]	0.35± 0.21	0.34± 0.20[c]	0.51± 0.20	0.52± 0.17	0.010[f]	<0.001[f]	<0.001[e]
Composite score	49.00±10.36	58.05± 16.55[d]	49.26±12.30	52.13± 12.51[d]	57.83±8.30	60.94± 9.87	0.018	0.048	0.026[e]
UST									
COP sway velocity (°/s)	3.18± 2.17	2.21± 1.88[a,d]	3.56± 1.85[b]	3.79± 1.77[b,c]	1.68± 0.70[a,c]	1.71± 1.06[a]	0.003[e]	0.001[e]	0.001[e]

Note. Values are mean ± SD or *p* values.

Among groups:

[a]Denotes a difference significant at $p \leq 0.01$when compared with the DCD-control group;

[b]Denotes a difference significant at $p \leq 0.01$when compared with the Normal-control group;

[c]Denotes a difference significant at $p \leq 0.01$when compared with the DCD-TKD group.

Within group (time effect):

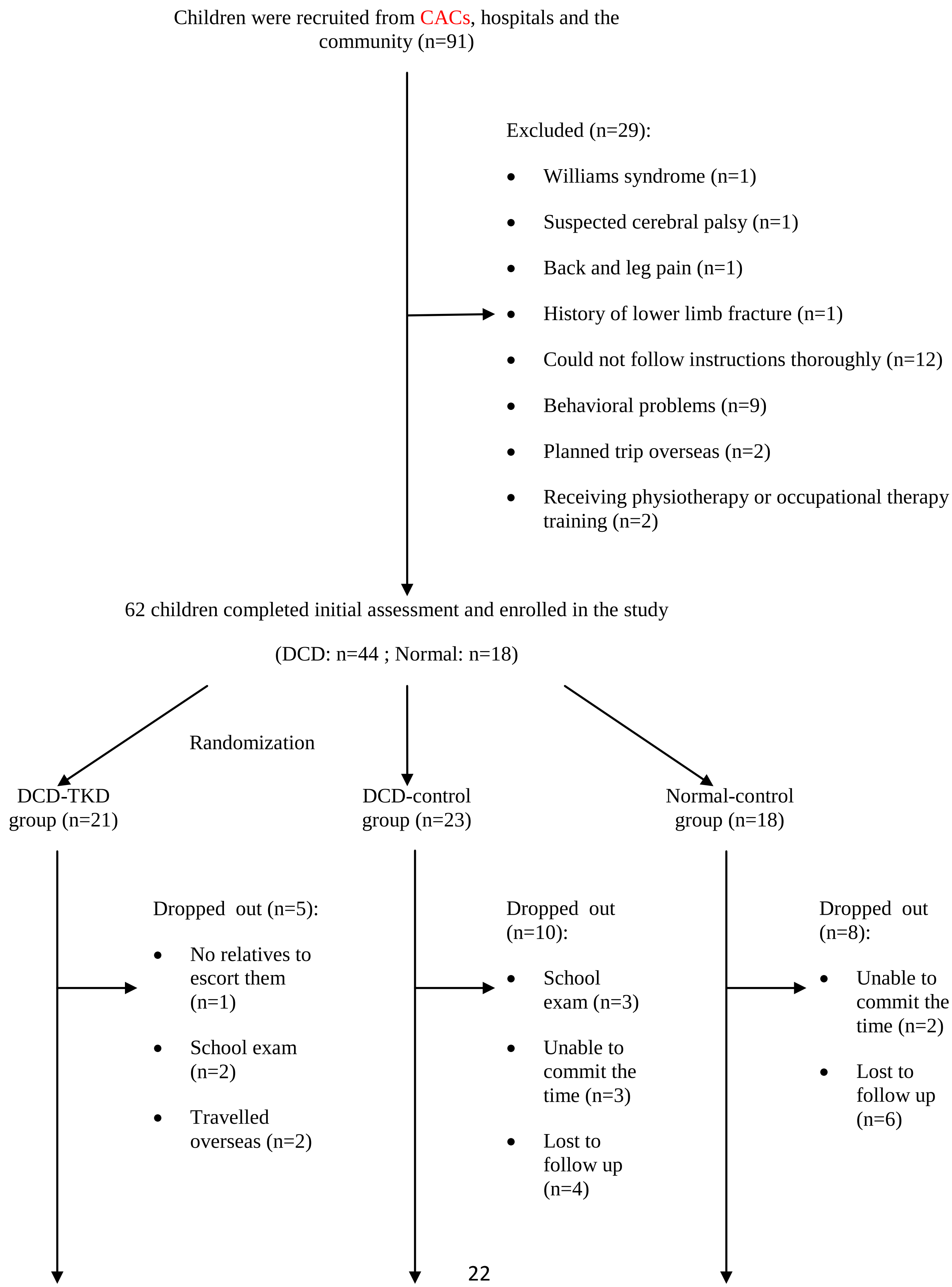
[d]Denotes a difference significant at $p \leq 0.05$ when compared with pretest values.

Group by time interaction and among three groups:

[e]Denotes a difference significant at the $p \leq 0.05$ confidence level.

[f]Denotes a difference significant at $p \leq 0.01$.

Figure 1. Study flowchart



Completed TKD training and follow-up assessment (n=16)	Completed follow-up assessment (n=13)	Completed follow-up assessment (n=10)