Effects of Cardiorespiratory Fitness Enhancement on Deficits in Visuospatial Working Memory in Children with Developmental Coordination Disorder: A Cognitive Electrophysiological Study

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Abstract

The present study aimed to explore the effectiveness of chronic aerobic exercise intervention on the behavioral and neuroelectric performances of children with developmental coordination disorder (DCD) when carrying out a visuospatial working memory (VSWM) task. Twenty typically developing children and 40 children with DCD, equally divided into DCD-training and DCD nontraining groups, performed the cognitive task with concomitant event-related potential recording before and after 16 weeks of endurance training. Results indicated that the children with DCD displayed VSWM deficits with regard to behavioral performance (i.e., slower reaction time and low accuracy rate) and the neuroelectric indices (i.e., smaller P3 and pSW amplitudes) during the retrieval-process phase as reported in previous studies. However, after the exercise intervention, DCD-training group showed significantly higher accuracy rates and enhanced P3 amplitudes during the encoding and retrieval-process phases, compared with their pre-training performances. These findings suggest that increased cardiorespiratory fitness could effectively improve the performance of the VSWM task in children with DCD, by enabling the allocation of greater working memory resources related to encoding and retrieval.

Keywords: Developmental coordination disorder; Event-related potential; Cardiorespiratory fitness; Working memory; Exercise intervention

Introduction

Although motor coordination impairment in children can result from a variety of known disorders, such as cerebral palsy, one group of children that also manifests such movement difficulties, which are not attributed to any medical condition or intellectual deficiencies, has been classified as having developmental coordination disorder (DCD) according to the fourth version of the Diagnostic and Statistical Manual of Mental Disorders (APA, 2000). The prevalence of DCD in school-aged children is estimated to be ~5%–6% (APA, 2000). Many studies have reported that children with DCD not only exhibit poor motor coordination in normal daily activities, but also experience educational underachievement and negative psychosocial repercussions, such as low self-esteem and self-concept, poor peer relations and participation in team sports, as well as emotional disorders (Skinner & Piek, 2001). These behavioral and psychosocial problems will persist into adolescence and even early adulthood (Cantell, Smyth, & Ahonen, 1994).

Since the deficits in behavioral and visual perceptual measures in children with DCD are most pronounced in the visuospatial tasks (Wilson & McKenzie, 1998), neuropsychological studies have adopted many different cognitive tasks with visuospatial components to gain deeper insights into the mechanisms of the potential neuropathology of DCD. For example, children with
DCD display a visuospatial deficit in shifts of voluntary/intentional attention when performing endogenous visuospatial attention tasks induced by arrow-directed cues (Tsai, 2009; Tsai, Pan, Cheng, Hsu, & Chiu, 2009; Tsai, Yu, Chen, & Wu, 2009; Wilson & Maruff, 1999), and a visuospatial deficit in dislocation of reflective/automatic attention when performing the exogenous visuospatial attention task induced by eye-gazed cues (Tsai, Pan, Chang, & Tseng, 2010; Tsai, Wang, & Tseng, 2012). Based on the results of brain event-related potential (ERP) measurements, the possible mechanisms underlying deficits of visuospatial attention could be attributed to less ability in interhemispheric transfer efficiency (i.e., smaller P3 amplitude) and a lower cognitive-to-motor transfer speed (i.e., elongated N2 latency – RT interval), as well as less mature abilities with regard to antipatorily executive and motor preparatory processes [small contingent negative variation (CNV) areas] in children with DCD as compared to typically developing (TD) children (Tsai, Pan et al., 2009; Tsai et al., 2010). In terms of tasks related to working memory (WM), children with DCD have also been found to exhibit selective deficits in visuospatial domains such as visuospatial working memory (VSWM), suggesting that they have specific problems with information processing and storage (Alloway, 2007; Alloway & Archibald, 2008; Alloway, Rejendran, & Archibald, 2009; Alloway & Temple, 2007). When performing the VSWM task coupled with ERP measures, children with DCD appear to allocate less resources for comparison of spatial locations (i.e., smaller P3 amplitude), as well as to response selection, [i.e., smaller positive slow wave (pSW) amplitude] and neural processing during the retrieval-process phase (i.e., there is less area under the curve of P3 and pSW components) when compared with TD children (Tsai, Chang, Hung, Tseng, & Chen, 2012). These atypical cognitive processing problems regarding visuospatial tasks in children with DCD suggest the possible neurological antecedents of this condition.

Physical exercise has a positive association with cognitive functions, since it strongly affects brain structure and neural plasticity (Hillman, Ericsson, & Kramer, 2008). However, the significant improvements in cognitive function induced by physical exercise seem to vary in size (Colcombe & Kramer, 2003), being greater for tasks requiring more extensive amounts of executive control and greater speed (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009). Therefore, two kinds of open-skill exercise modes (table tennis and soccer) have been used to improve the deficits of inhibitory control in children with DCD when performing the endogenous visuospatial attention task using the upper limbs (Tsai, 2009) or performing the exogenous visuospatial attention task using the lower limbs (Tsai, Wang et al., 2012). After a 10-week exercise intervention program employed within a school setting, the behavioral [e.g., motor performance in Movement Assessment Battery for Children (M-ABC) test, reaction time, and inhibitory control], and neuroelectric (e.g., P3 latency) parameters of the study subjects improved significantly (Tsai, 2009; Tsai, Wang et al., 2012). Both studies supported the view that physical exercise seems to be an effective way to enhance motor outcomes in an ecological setting (e.g., school, community, or family), as well as alleviate the deficits of the cortical processing pathways in children with DCD (Tsai, Wilson, & Wu, 2008). Since the development of the VSWM network follows an inverted U-shaped course, with an increase during childhood followed by a decrease in adolescence and stabilization in adulthood (Shaw et al., 2008), this VSWM deficit also seems to be remediable via regular physical exercise intervention during childhood.

Endurance training can not only enhance cardiorespiratory fitness, but also increase cerebral blood flow (Seifert & Secher, 2011), cerebral structure (Colcombe et al., 2003), and brain-derived neurotrophic factors (Seifert et al., 2010), which are thought to be related with cognitive performance (Sohn, Chung & Jang et al., 2005). A previous study demonstrated that children with higher cardiorespiratory fitness exhibited a superior ability to activate the frontal and parietal regions important for higher level cognitive functioning, suggesting that aerobic fitness in children is associated with the modulation of brain circuits involved in cognitive control (Chaddock et al., 2012). Indeed, regardless of acute or long-term intervention, such an exercise mode can effectively improve various aspects of memory performance. For example, Pesce, Crova, Cereatti, Casella, & Bellucci (2009) found that a 40-min acute aerobic exercise intervention led to better memory performance than did a nonexercise intervention condition in preadolescents. In terms of long-term endurance training, Kamijo and colleagues (2011) observed that physical activity intervention aimed at improving cardiorespiratory fitness is associated with improvements in the behavioral (e.g., response accuracy) and cognitive electrophysiological (e.g., CNV component) performance of WM in preadolescent children. The potential mechanisms through which increased cardiorespiratory fitness can improve memory function could be that hippocampal neurogenesis and volume, synaptic plasticity, and learning are regulated by the effects of endurance exercise training (Erickson et al., 2009). Although children with DCD exhibit deficits in VSWM, as mentioned above, these problems with cognitive processing could be remediable via physical exercise (Tsai, 2009; Tsai, Wang, et al., 2012). It is thus likely that enhanced physical activity that aims to increase cardiorespiratory fitness can influence the acquisition and development of the related cognitive networks during childhood (Kamijo et al., 2011; Pesce et al., 2009), since the cognitive functions involving VSWM are still developing at this time (Myatchin & Lagae, 2013).

Deficits in VSWM in children with DCD have been demonstrated in many previous studies (Alloway, 2007; Alloway & Archibald, 2008; Alloway et al., 2009; Alloway & Temple, 2007; Tsai, Chang, et al., 2012). However, thus far, no research has yet been conducted that explores the effectiveness of long-term exercise intervention on the behavioral and neuroelectric performances in children with DCD when performing a VSWM task. ERPs can permit online measures of human information processing streams on the order of milliseconds, and reflect the changing voltage patterns that occur in ongoing neuroelectric activity
(Hillman, Castelli, & Buck, 2005). These neuroelectric changes can provide insights into the underlying mechanisms related to discrete cognitive processes during stimulus encoding and response execution when individuals perform VSTM tasks, and are influenced by chronic aerobic exercise (Kamijo et al., 2011). Therefore, the objective of the current study was to investigate whether a 16-week endurance exercise intervention could effectively improve the behavioral and ERP indices in children with DCD when performing a spatial delayed matching-to-sample task, which includes both nondelayed and two-time-delayed spatial working memory conditions. Based on the literature reviewed above, exercise training designed to promote increases in cardiorespiratory fitness seems to be an effective way to improve VSTM performance in children (Pesce et al., 2009; Kamijo et al., 2011). It could thus be assumed that chronic endurance exercise intervention would have a beneficial effect on the deficits of overt behavioral task performance and the neuroelectric indices of a VSTM cognitive task in children with DCD.

Method

Participants

One thousand and ninety-six school children aged 11–12 were recruited from three urban schools located in different geographic locations of Taiwan using stratified random selection for sampling. The children were attending mainstream classrooms, and none of them had any evident signs of physical or behavioral problems, evident neurological damage, or special needs in education, as assessed by pediatricians, that would qualify as exclusionary criteria. Each child was screened using the M-ABC-second Edition (M-ABC-2) test, and then categorized into one of three groups: typically developing (TD, n = 975, scoring above the 15th percentile), borderline DCD (n = 79), and DCD (n = 42, scoring below the 5th percentile). The parents and teachers reported that the poor motor coordination of the children with DCD did indeed interfere with their academic achievement and daily activities, based on their performance at school and home. Additionally, due to the comorbidity of DCD and attention deficit hyperactivity disorder (ADHD) reported in a previous study (Chen, Tseng, Hu, & Cermak, 2009), the parents and teachers of all the participants were asked to complete a brief behavior rating scale (Dupaul, Power, Anastopoulos, & Reid, 1998) based on the DSM-IV criteria for ADHD, according to the children’s behavioral patterns in the previous 6 months. Two of children with DCD were identified as having ADHD, and thus excluded from this study. Based on the screening method, all the children with DCD met the clinical DSM-IV-TR criteria for this condition. The participant selection procedure was carried out using a previously validated method (Tsai, Chang, et al., 2012; Tsai, Wang, et al., 2012).

Forty children with DCD were then quasi-randomly subdivided into the DCD-training group (n = 20) or DCD non-training group in accordance with the children’s and their parents’ consent. Twenty age-matched TD children were randomly selected from the TD group. All experimental participants were assessed as right-handed using the Edinburgh Inventory, and had normal or corrected-to-normal vision acuity. The children’s IQs were also assessed using the WISC-R (Wechsler, 1992), and all fell within normal intelligence quotient scores [F(2, 57) = 0.55, p = .581 across all three groups]. The body mass index was also not significantly different across all three groups [F(2, 57) = 1.79, p = .176], as seen in Table 1. The experiment was approved by the Ethical Committee of the Medical Faculty of National Cheng Kung University in Taiwan. Prior to the start of the experiment, written informed consent was obtained from one parent of each child, and assent was also given by the children, who were free to withdraw at any time.

Procedures

The motor skills (i.e., the M-ABC-2 test) and cognitive neuropsychological performance using the VSTM paradigm were assessed individually before and after cardiorespiratory endurance training. The motor skills tests were administered by three research assistants who had extensive experience in assessing children’s motor functioning and had majored in physical therapy or

<table>
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<tr>
<th>Table 1. The demographic characteristics, IQ scores, and ADHD behavior rating scale performances of the three groups</th>
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<td>Age (months)</td>
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<td>DCD-training</td>
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<td>DCD non-training</td>
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Notes: M-ABC = Movement Assessment Battery for Children; IQ = intelligence quotient; ADHD = attention deficit hyperactivity disorder; DCD = developmental coordination disorder; TD = typically developing.
adapted physical education. The cognitive neuropsychological performance was examined via objective measures by an independent evaluator who was blind to the children’s group membership before and after the exercise intervention. The criteria of overt behavioral and cognitive neuropsychological measurement used for the experimental period were kept identical in both sessions, before and after cardiorespiratory endurance training.

In terms of the cognitive neuropsychological measure, when the child arrived at an acoustically shielded laboratory with dimmed lights, the experimenter asked him or her to sit comfortably in an adjustable chair in front of a computer screen placed at face level and at a distance of $\approx 75$ cm. The experimental procedure was then explained to the child until they understood the whole process and was familiar with the task, with a practice block of 10 trials being carried out to ensure this. The experimenter was seated next to the child to monitor his or her visual fixation to encourage him or her to avoid saccades with regard to the laterally presented stimuli. Specifically, if the child’s eye moved away from the central fixation cross during the execution of the response, then verbal encouragement was given to look at the screen. When the child understood the whole experimental procedure, the electrocap and electro-oculographic electrodes were attached to his or her head and face, and the formal VSWM task was then administered. The child was asked to respond as quickly and accurately as possible when performing the cognitive task, with concomitant ERP recording.

The Visuospatial Working Memory Paradigm (Tsai, Chang, et al., 2012)

The procedure is summarized graphically in Fig. 1. The VSWM paradigm has been used in Tsai, Chang and colleagues (2012), which was adapted from that in Muller and Knight (2002). The stimuli consisted of two red ladybugs (diameter 15 mm) randomly presented in a $4 \times 7$ matrix within a grey rectangle ($4.6^{\circ} \times 8.0^{\circ}$), which was either presented in the center of the screen or $5.9^{\circ}$ to the right or left of the central fixation point. The rectangles and ladybugs were either presented simultaneously or consecutively, giving the following three conditions: (i) a spatial nondelay task (i.e., the attention task) where two rectangles, one placed in the center of the screen and one either to the right or the left of the first rectangle, simultaneously appeared for 180 ms, with this time chosen as it is shorter than a typical saccade latency (Muller & Knight, 2002). The children had to compare the positions and directions of the ladybugs in the rectangles; (ii) two spatial memory tasks with a 3s-delay or (iii) with a 6s-delay, where the rectangles and ladybugs appeared with the respective delays. The first stimulus (S1) appeared either on the right or left side of a central fixation cross ($0.5^{\circ} \times 0.5^{\circ}$) for 180 ms, with the rectangles placed at the same positions as in the attention task. After a delay of 3s or 6s, during which the child was told to keep their attention fixed on the central cross, the cross was replaced by a second rectangle and ladybugs (S2) for 500 ms. The child then needed to recall within 2s whether the relative positions and directions of the four ladybugs within separate
rectangles matched or not. Upon detection of the stimuli, the child was instructed to press the “N” key on a computer keyboard as quickly as possible if the positions seemed identical, or the “M” key if they seemed different, using the index or middle fingers of the dominant hand. One of three kinds of feedback (correct, false, or no response) was provided after the child responded correctly, wrongly, or did not respond after 2s. The next trial then started 1000 ms later with the announcement of “next trial.” A total of 324 trials were included in the experimental session, which was divided into three consecutive blocks of 108 trials, with a 3-min rest in between, during which the child remained at the workstation. The three tasks were presented randomly and in an equiprobably intermingled order in each block. All stimuli were presented on a 21-in. CRT display against a black background using STIM software (Neuroscan Ltd., El Paso, USA).

Cardiorespiratory Fitness Test

The progressive aerobic cardiovascular endurance running (PACER) test in the Brockport Physical Fitness Test Kit (Human Kinetics, Champaign, IL, USA) provides a reliable and valid field test against directly measured maximal oxygen consumption in children and adolescents (Leger, Mercier, Gadoury, & Lambert, 1988). The PACER test, a multistage progressive 20-m shuttle run test, was thus used to assess cardiorespiratory fitness in this study. After the details of the PACER protocol were explained before the start of the test, children were asked to run between two lines 20-m apart using the cadence dictated by a CD emitting audible signals at prescribed intervals. In the first minute, the initial running speed was set at 8.5 km/h, and this was then increased by 0.5 km/h each subsequent minute. When a child failed to keep up with the pace by reaching the line at the time of the tone, the test was terminated at the second fault and the number of laps completed was recorded. The cardiorespiratory fitness was scored as the number of shuttle runs completed at volitional exhaustion in the PACER test.

Endurance Training Program

The children in the DCD-training group were involved in an endurance training program in a series of 50-min sessions conducted three times per week at school for 16 weeks, while the DCD nontraining and TD groups performed their regular classroom activities and did not participate in any training for the duration of this study. An adapted physical education teacher who had extensive experience of physical fitness training in children of primary school age, and was blind to the participants’ characteristics of motor impairment, was in charge of the endurance training for the DCD-training group. The endurance training program consisted of interval training (repeated work-recovery bouts over short distance: 5 × 100 m, 3 × 200 m, 2 × 600 m) and one continuous long-distance running session, and one session with another aerobic activity (e.g., cycling, step aerobics, or rope jumping). The distance, speed, and number of repetitions were gradually increased throughout the training period according to each child’s ability. During each session, each child was fitted with a Polar heart rate monitor (RX800CX, Finland) to ascertain that the training intensity was attained (i.e., between 80 and 90% of each child’s maximal heart rate). During the 50-min training, the children spent around 25–30 min on average in the target zone. The endurance training program was organized on the basis of competitions and games with different groups of three to five children with similar maximal aerobic velocities. This training prescription has been demonstrated to effectively increase cardiorespiratory endurance among children (Mandigout, Lecoq, Courteix, Guenon, & Obert, 2001). The average rate of adherence to the exercise training was ~100% (99.47 ± 0.69%) in the DCD-training group in the present study.

Psychophysiological Recording and Processing Methods

The electroencephalographic activity, as well as blinks and saccades, was recorded from 18 scalp sites (F7, F8, F3, F4, Fz, T3, T4, C3, C4, Cz, T5, T6, P3, P4, Pz, O1, O2, Oz) using Ag/AgCl sintered electrodes mounted in an elastic cap (Quik-Cap, Neuroscan, Inc., El Paso, TX, USA) according to the International 10/20 System. The adhesive electrodes were placed on the supero-lateral right canthus and below and lateral to the left eye, and connected to the system with reference to the horizontal and vertical electro-oculograms (i.e., HEOG and VEOG) activity in order to monitor eye movements. All rows of electrode recordings were referenced online to an external electrode, which was placed on the mastoid. A ground electrode was placed on the midforehead upon the Quik-Cap. The impedances were maintained <5 kΩ. The bio-signals were amplified using a 0.1–50 Hz band-pass notch filter and continuously sampled at an A/D rate of 500 Hz/channel for off-line analysis using SCAN4.3 analysis software (Compumedics Neuroscan, Inc., El Paso, TX, USA). Stimulus timing and recording of behavioral data were controlled using a neuro-stimulation system (Neuroscan Ltd.).

For ERP signal processing, the ERP components and time windows used in this work were based on those in a previous study (Tsai, Chang et al., 2012). Initially, each EEG epoch was visually inspected, and rejected if it contained EEG artifacts (e.g., VEOG, HEOG, and electromyogram exceeded 100 μV peak-to-peak amplitude) or excessive movement before averaging. The
remaining, effective data were then separately averaged off-line, using a ± 100 μV automatic artifact rejection. The baseline was the mean voltage of a 100 ms pre-stimulus interval. Each EEG epoch in the time window of 100 ms before S1 to 1600 ms after S2 onset was computed and averaged for the different memory load conditions. According to a previous study (Tsai, Chang et al., 2012), the most distinct modulatory effects exhibited by the TD and DCD groups are for the smaller P3 (defined as the maximum positive deflection occurring 300–500 ms after the S2 stimulus) and pSW (defined as the major positive deflection occurring 700–820 ms after the S2 stimulus) (Garcia-Larrea & Cezanne-Bert, 1998) amplitudes in memory tasks. The effects of the exercise intervention on these ERP indices was thus highlighted in this study by examining changes in the amplitudes of the P3 and pSW components in two time-delayed conditions. In addition, since the parietal lobe has a crucial role in spatial delayed matching-to-sample tasks (Garcia-Larrea & Cezanne-Bert, 1998; Muller & Knight, 2002), and children with DCD, when performing the VSWM task, exhibit significant deficits in the centroparietal scalp region, the Pz electrode was used to analyze the ERP data (Tsai, Chang et al., 2012).

Data Analysis

Mixed-model MANOVA with repeated measures was used to analyze the training effect, with the time of assessment (pre- and post-training) as the within-subjects factor and group as the between-subjects factor, using the M-ABC-2 scores, cardiorespiratory fitness, mean RTs, response accuracy, and separate ERP parameters (i.e., P3 and pSW amplitudes) for correct answers as the dependent variables. Post-hoc contrasts were used to determine the interaction effects within the three groups. To control for any differences that might have existed prior to the cardiorespiratory endurance training, post-training data always accounted for pre-training data using an analysis of covariance (ANCOVA) procedure. The averaged pre-training measures were used as the covariate (Tsai, 2009; Tsai, Wang et al., 2012). The significance level was set at 0.05 for all analyses. Post-hoc comparisons relied upon the Bonferroni procedure. Homogeneity and normality of variance assumptions were confirmed by Levene’s and Kolmogorov–Smirnov tests, respectively. The significance levels of the F ratios were adjusted with the Greenhouse–Geisser correction for the violation of the assumption of sphericity when the degrees of freedom were more than one. The effect size (i.e., partial $\eta^2$: $\eta^2_p$) is also reported to complement the use of significance testing. The following conventions were adopted to determine the magnitude of the mean effect size: < 0.08 (small effect size), between 0.08 and 0.14 (medium effect size), and > 0.14 (large effect size) (Bora, Vahip, & Akdeniz, 2006).

Results

Cardiorespiratory Fitness

As shown in Table 2, the analysis of the cardiorespiratory fitness of the three groups measured with PACER indicated that the group $F(2,57) = 42.77$, $p < .001$, $\eta^2_p = 0.60$, time $F(1,57) = 97.60$, $p < .001$, $\eta^2_p = 0.63$ and group × time $F(2,57) = 23.33$, $p < .001$, $\eta^2_p = 0.45$, all produced significant F-ratios. The interaction was investigated with simple main effects to determine the difference in cardiorespiratory fitness before and after training.

Pre-Training. The results revealed significant group differences in cardiorespiratory fitness $F(2,57) = 47.40$, $p < .001$. Post-hoc tests showed that both DCD groups performed significantly worse than the TD group (both $p < .001$), but there were no significant differences between the DCD groups ($p = .972$).

Post-Training. The results of ANCOVA indicated a significant group difference in post-training cardiorespiratory fitness $F(2,56) = 22.48$, $p < .001$, $\eta^2_p = 0.45$, with the DCD nontraining group performing significantly worse than the DCD-training ($p < .001$) and TD (p = .031) groups. In addition, a significant difference was also found between the DCD-training and TD groups ($p = .027$). The results of the paired-samples t-test indicate that the cardiorespiratory fitness of DCD-training and TD groups improved over time [DCD-training: $t(19) = -8.89, p < .001$; TD: $t(19) = -4.72, p < .001$].

Motor Ability (M-ABC-2 Test)

Group $F(2,57) = 356.75$, $p < .001$, $\eta^2_p = 0.93$, time $F(1,57) = 63.36$, $p < .001$, $\eta^2_p = 0.53$, and group × time $F(2,57) = 54.72$, $p < .001$, $\eta^2_p = 0.66$ produced significant F-ratios. The interaction was investigated with simple main effects to determine the difference in motor performances before and after training.
Pre-Training. The results revealed significant group differences in motor abilities \( F(2,57) = 397.12, p < .001 \). Post-hoc tests showed that both DCD groups performed significantly worse than the TD group (both \( p < .001 \)), but there were no significant differences between the DCD groups \( (p = .978) \).

Post-Training. The results of ANCOVA indicated a significant group difference in post-training motor performance \( F(2,56) = 50.95, p < .001, \eta^2_p = 0.65 \), with the DCD nontraining group performing significantly worse than the DCD-training \( (p < .001) \) and TD groups \( (p = .006) \). The results of the paired-samples \( t \)-test indicate that the motor performance of the DCD-training group improved over time \( t(19) = -8.54, p < .001 \), but this was not seen for the DCD nontraining group \( t(19) = 0.70, p = .493 \) or TD group \( t(19) = -2.02, p = .058 \).

**Behavioral Performance**

**Response accuracy.** Group \( F(2,57) = 11.28, p < .001, \eta^2_p = 0.28 \) and time \( F(1,57) = 5.83, p = .019, \eta^2_p = 0.09 \) produced significant main effects reflecting the facts that the TD group responded more accurately overall than did both DCD groups across all three conditions, and that all children made fewer errors after training. There was also an effect of condition \( F(2,114) = 169.46, p < .001, \eta^2_p = 0.75 \) on the response accuracy. In addition, the time \( \times \) group \( F(2,57) = 3.61, p = .033, \eta^2_p = 0.11 \), group \( \times \) condition \( F(4,114) = 3.31, p = .013, \eta^2_p = 0.10 \) and time \( \times \) group \( \times \) condition \( F(4,114) = 2.70, p = .034, \eta^2_p = 0.09 \) interactions also yielded reliable effects. The three interaction effects were investigated with the simple main effects with the pre- and post-training data, respectively.

Pre-Training. The analysis of the response accuracy before training showed significant group differences \( F(2,57) = 11.70, p < .001, \eta^2_p = 0.29 \), indicating that both DCD groups made more errors than the TD group (both \( p < .001 \), but there was no significant differences between the DCD groups \( (p = .860) \). In addition, the condition \( F(2,114) = 92.46, p < .001, \eta^2_p = 0.62 \) and group \( \times \) condition \( F(4,114) = 2.48, p = .048, \eta^2_p = 0.08 \) both produced significant \( F \)-ratios. Post-hoc tests showed that both DCD groups performed less accurately in the 3s- and 6s-delayed conditions, but not in the nondelayed condition, when compared with the TD group.

### Table 2. Cardiorespiratory fitness (the number of laps completed in the PACER test), M-ABC-2 scores, mean reaction times (ms) and overall response accuracy (% of the visuospatial working memory paradigm for the three groups (DCD-training group, DCD nontraining group, and TD group) at the pre- and post-training conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>DCD-training (( n = 20 ))</th>
<th>DCD nontraining (( n = 20 ))</th>
<th>TD (( n = 20 ))</th>
<th>Significant difference</th>
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<tr>
<td><strong>Pre-training</strong></td>
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<tr>
<td>Cardiorespiratory fitness</td>
<td>17.35 ± 8.73</td>
<td>18.30 ± 10.41</td>
<td>51.25 ± 16.95</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
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<tr>
<td>M-ABC-2 test</td>
<td>48.93 ± 5.36</td>
<td>49.30 ± 5.36</td>
<td>92.45 ± 6.09</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
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<td><strong>Response accuracy</strong></td>
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<tr>
<td>Non-delayed</td>
<td>87.31 ± 5.15</td>
<td>86.18 ± 5.41</td>
<td>89.83 ± 5.49</td>
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<tr>
<td>3s-delayed</td>
<td>78.95 ± 6.94</td>
<td>79.81 ± 6.70</td>
<td>86.88 ± 6.63</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
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<tr>
<td>6s-delayed</td>
<td>73.43 ± 6.33</td>
<td>72.90 ± 6.26</td>
<td>81.39 ± 6.05</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
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<tr>
<td><strong>Reaction time</strong></td>
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<tr>
<td>Non-delayed</td>
<td>606.03 ± 94.56</td>
<td>597.01 ± 81.06</td>
<td>584.37 ± 62.20</td>
<td>—</td>
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<tr>
<td>3s-delayed</td>
<td>881.72 ± 55.84</td>
<td>883.63 ± 59.81</td>
<td>831.88 ± 53.10</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
</tr>
<tr>
<td>6s-delayed</td>
<td>871.56 ± 49.05</td>
<td>875.21 ± 58.22</td>
<td>827.86 ± 53.47</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
</tr>
<tr>
<td><strong>Post-training</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiorespiratory fitness</td>
<td>42.50 ± 11.95</td>
<td>21.35 ± 6.61</td>
<td>62.60 ± 23.12</td>
<td>TD &amp; DCD-training &gt; DCD non-training</td>
</tr>
<tr>
<td>M-ABC-2 test</td>
<td>68.70 ± 8.97</td>
<td>48.68 ± 6.88</td>
<td>94.13 ± 5.30</td>
<td>TD &amp; DCD-training &gt; DCD non-training</td>
</tr>
<tr>
<td><strong>Response accuracy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-delayed</td>
<td>87.39 ± 5.47</td>
<td>86.74 ± 5.47</td>
<td>90.29 ± 5.34</td>
<td>—</td>
</tr>
<tr>
<td>3s-delayed</td>
<td>86.47 ± 7.14</td>
<td>79.64 ± 7.95</td>
<td>87.06 ± 7.89</td>
<td>TD &amp; DCD-training &gt; DCD non-training</td>
</tr>
<tr>
<td>6s-delayed</td>
<td>80.44 ± 7.66</td>
<td>73.51 ± 7.34</td>
<td>82.17 ± 6.80</td>
<td>TD &amp; DCD-training &gt; DCD non-training</td>
</tr>
<tr>
<td><strong>Reaction time</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-delayed</td>
<td>573.68 ± 67.96</td>
<td>593.14 ± 55.82</td>
<td>567.64 ± 38.61</td>
<td>—</td>
</tr>
<tr>
<td>3s-delayed</td>
<td>883.13 ± 56.76</td>
<td>899.25 ± 51.27</td>
<td>828.87 ± 44.55</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
</tr>
<tr>
<td>6s-delayed</td>
<td>866.26 ± 42.40</td>
<td>882.95 ± 42.92</td>
<td>816.03 ± 67.21</td>
<td>TD &gt; DCD-training &amp; DCD non-training</td>
</tr>
</tbody>
</table>

Notes: DCD = developmental coordination disorder; TD = typically developing; M-ABC-2 = Movement Assessment Battery for Children-2nd edition; Pre- vs. Post-training improvement in DCD-training group = cardiorespiratory fitness, M-ABC-2 test, & Response accuracy in 3s- and 6s-delayed conditions.
**Post-Training.** The results of ANCOVA indicated significant group differences in 3s- \[F(2,56) = 4.86, p = .011, \eta^2_p = 0.15\] and 6s-delayed \[F(2,56) = 5.327, p = .008, \eta^2_p = 0.16\] conditions in post-training performance. After post-hoc comparisons, the effect value of response accuracy was significantly smaller in the DCD nontraining group than in the DCD-training (3s-delay: \(p = .005\); 6s-delay: \(p = .004\)) and TD (3s-delay: \(p = .026\); 6s-delay: \(p = .015\)) groups, but a significant difference was not found between the DCD-training and TD groups (both memory conditions: \(p > .05\)). The results of the paired-samples t-test indicate that only the response accuracy of the DCD-training group improved over time [3s-delay: \(t(19) = -3.66, p = .002; 6s\text{-delay: } t(19) = -3.05, p = .007\].

**Reaction time (RT).** Group \([F(2,57) = 7.98, p = .001, \eta^2_p = 0.22]\) and condition \([F(2,57) = 1359.05, p < .001, \eta^2_p = 0.96]\) produced significant main effects. Post-hoc comparisons reflected that both the DCD-training and DCD nontraining groups responded more slowly overall than did the TD group. In addition, the condition \(\times\) group \([F(4,114) = 2.91, p = .025, \eta^2_p = 0.09]\) interaction also yielded a reliable effect. Post-hoc tests showed that both DCD groups were significantly slower in the 3s- and 6s-delayed conditions, but not in the nondelayed condition.

**ERPs Results**

**S1-Evoked P3 amplitude in the 3s- and 6s-delayed conditions.** The grand-average ERP waveforms are shown in Fig. 2. During the encoding phase in the two memory conditions, time \([F(1,57) = 23.70, p < .001, \eta^2_p = 0.29]\) and condition \([F(1,57) = 4.28, p = .043, \eta^2_p = 0.07]\) produced significant main effects. In addition, the time \(\times\) group \([F(2,57) = 6.48, p = .003, \eta^2_p = 0.19]\) interaction also yielded a reliable effect, and this was investigated using the simple main effects with the pre- and post-training data.

**Pre-Training.** No significant differences were observed between the three groups in the averaged S1-evoked P3 amplitude in both the 3s- and 6s-delayed conditions during the encoding phase.

![Fig. 2.](image-url) Grand-average event-related potential waveforms. Average waveforms of Pz electrode in 3s- and 6s-delayed conditions before (left) and after exercise (right).
**Post-Training.** The averaged S1-evoked P3 amplitude in both 3s- and 6s-delayed conditions after training indicated a significant group difference \( F(2,57) = 7.67, p = .001 \). After post-hoc comparisons, the effect value was significantly larger in the DCD-training (21.00 ± 6.26 \( \mu V \), \( p = .005 \)) and TD (20.95 ± 6.99 \( \mu V \), \( p = .005 \)) groups than in the DCD nontraining group (14.28 ± 5.35 \( \mu V \)), but a difference was not found between the DCD-training and TD groups (\( p = 1.000 \)).

**S2-evoked P3 amplitude in the 3s- and 6s-delayed conditions.** During the response phase, group \( F(2,57) = 8.04, p = .001, \eta^2_p = 0.22 \), time \( F(1,57) = 22.81, p < .001, \eta^2_p = 0.29 \), and condition \( F(1,57) = 37.19, p < .001, \eta^2_p = 0.40 \) produced significant main effects. In addition, the time × group \( F(2,57) = 3.26, p = .046, \eta^2_p = 0.10 \) and group × condition \( F(2,57) = 4.87, p = .011, \eta^2_p = 0.15 \) interactions also yielded a reliable effect. The two interaction effects were investigated using the simple main effects with the pre- and post-training data.

**Pre-Training.** An effect of group was observed on the amplitude of the S2-evoked P3 component \( F(2,57) = 4.00, p = .024, \eta^2_p = 0.12 \) during the retrieval-process phase across all three conditions, with smaller amplitudes in both the DCD groups in comparison with the TD group. Post-hoc tests showed that the difference between the three groups was significantly greater in the TD group (18.40 \( \mu V \)) than in both the DCD-training (13.71 \( \mu V \)) and DCD nontraining (13.61 \( \mu V \)) groups.

**Post-Training.** The results of ANCOVA indicated a significant group difference in post-training P3 amplitude \( F(2,56) = 6.20, p = .004, \eta^2_p = 0.18 \). Post-hoc tests showed that mean S2-evoked P3 amplitude was significantly smaller in the DCD nontraining group (15.93 \( \mu V \)) than in the DCD-training (23.67 \( \mu V \)) and TD (23.69 \( \mu V \)) groups.

**S2-evoked pSW amplitude in the 3s- and 6s-delayed conditions.** During the response phase, time \( F(1,57) = 6.05, p = .017, \eta^2_p = 0.29 \) and condition \( F(1,57) = 6.54, p = .013, \eta^2_p = 0.10 \) produced significant main effects. In addition, the time × group \( F(2,57) = 5.28, p = .008, \eta^2_p = 0.16 \) interaction also yielded a reliable effect, which was investigated using the simple main effects with the pre- and post-training data.

**Pre-Training.** An effect of group was observed on the averaged amplitude of the S2-evoked pSW component \( F(2,57) = 5.68, p = .006 \) during the retrieval-process phase across all three conditions, with smaller amplitudes in the both DCD groups in comparison with the TD group. Post-hoc tests showed that the difference between the three groups was significantly greater in the TD group (19.49 \( \mu V \)) than in both DCD-training (14.54 \( \mu V \)) and DCD nontraining (14.47 \( \mu V \)) groups.

**Post-Training.** The results of ANCOVA indicated no significant group difference on the averaged S2-evoked pSW amplitude in both 3s- and 6s-delayed conditions across the post-training period.

**Discussion**

The principal object of this study was to investigate whether a 16-week endurance exercise intervention designed to promote increases in cardiorespiratory fitness would improve the motor and VSWM performance in children with DCD on six dimensions: M-ABC-2 scores, response accuracy, RT, P3, and pSW amplitudes in 3s- and 6s-delayed conditions. Overall, children with DCD exhibited poor cardiorespiratory fitness, longer RTs, and lower accuracy rates only in the memory tasks, as well as distinct modulatory effects upon smaller P3 and pSW amplitudes during the retrieval-process period when compared with TD children before training, which corroborate the findings obtained in a previous study (Tsai, Chang et al., 2012). Although the post-training results did not identify any significant effect of the endurance exercise intervention on the RTs and pSW components during the retrieval-process phase in children with DCD, training-related improvements were observed in motor abilities when performing the M-ABC-2 tests, response accuracy, and P3 amplitudes during the encoding and retrieval-process phases in these children, which proves that the neuronal network supporting visuospatial working memory could be strengthened by appropriate exercise interventions in children with DCD.

Response speed is positively related to cardiorespiratory fitness in children when performing cognitive tasks (Hillman et al., 2005). A previous study found that high-fitness children showed faster RTs than low-fitness children when they performed a stimulus discrimination task, suggesting that the former had better cognitive processing speed (Hillman et al., 2005). The fact that the DCD population has lower cardiorespiratory fitness levels has been demonstrated in numerous previous studies (for a review of these, see Rivilis et al., 2011), as well as in the present work. Although children with DCD performed similar RTs relative to the TD children in the nondelayed spatial task, they showed significantly slower RTs when performing time-delayed spatial WM tasks. This pattern of results is in accordance with the results of Tsai, Chang and colleagues (2012), demonstrating that, in spite of the fact that children with DCD showed similar executive speeds in spatial information processing when performing the nondelayed...
spatial task when compared with TD children, they displayed a generalized reduction in the time efficiency of the central processing of cognitive functions when encountering the VSWM tasks involving greater temporal demands. However, the executive speed in encoding and retrieval functions did not improve in the DCD-training group after cardiorespiratory fitness improvement. Although a previous study found that beneficial effects on RT latency could be observed immediately and 30 min after acute aerobic exercise in preadolescent children when performing a modified Sternberg task, which was used to assess the executive control of WM (Pontifex, Hillman, Fernhall, Thompson, & Valentine, 2009), novel to this work was the inclusion of a chronic aerobic exercise intervention in children with DCD, the effects of which were unrelated to the RT changes in VSWM. It may be possible that this null result could be attributed to the WM loads for the children with DCD, especially with the visuospatial component involved in this study, which is the significant impairment for the DCD group (Tsai, 2009; Tsai, Pan et al., 2009; Tsai et al., 2010; Tsai, Yu, et al., 2009; Tsai, Wang, et al., 2012; Wilson & Maruff, 1999). These children thus need more time to accomplish the processes of encoding and retrieving information. Additionally, the differential effects of acute and chronic exercise intervention on cognitive performance could be another possible explanation for the different findings. In general, the exercise-induced arousal following an acute bout of exercise can facilitate the motor processes inherent in responding by means of activating the cortical regions that modulate attentional, motor, and sensory processes (Tomporowski, Lambourne, & Okumura, 2011). However, since the arousal effect elicited by the change in serum cortisol concentration only lasts for about 1 h (Heaney, Carroll, & Phillips, 2013), such a mechanism for the beneficial effect of acute aerobic exercise on motor response appears insensitive to the effects of chronic exercise. Additionally, the unimproved executive speed in children with DCD in the present study was not in accordance with the findings of previous studies (Tsai, 2009; Tsai, Wang, et al., 2012), which found that such children could improve their executive speed with a long-term exercise intervention when performing cognitive tasks related to visuospatial attention. It may be that these discrepant findings are a result of differences in exercise modes, since open-skill (e.g., soccer and table tennis) relative to closed-skill (e.g., running) exercises can partially compensate for executive speed impairment in individuals with disabilities (Di Russo et al., 2010). Along these lines, it would be informative to further examine the effects of open-skill exercise coupled with cardiorespiratory fitness enhancement on the executive speed of the VSWM task in children with DCD.

Regarding the response accuracy of the VSWM task, before the exercise intervention both DCD groups performed less accurately in the 3s- and 6s-delayed conditions, but not in the nondelayed one, when compared with the TD group. These findings could suggest that, notwithstanding the fact that neither DCD group showed any impairment in spatial information processing in the nondelayed spatial task, their encoding and retrieval functions could be compromised when encountering VSWM tasks involving greater temporal demands. This is compatible with Tsai, Chang and colleagues (2012) finding of a significant discrepancy between the scores of DCD and TD groups when performing the VSWM task. Even though the response accuracies of the three groups decreased from the 3s- to 6s-delayed conditions in the expected fashion, and the DCD-training group did not see any significant improvement in RT latency, increases in cardiorespiratory fitness resulting from the 16-week endurance training intervention led to improvements in accuracy rates for both memory conditions in the DCD-training group, with no such effect observed for the DCD nontraining group. Indeed, Chaddock and colleagues (2012) demonstrated that aerobically fit children exhibit superior cognitive performance (i.e., response accuracy) relative to less fit children when performing an executive control task. Additionally, in agreement with a previous study (Kamijo et al., 2011), it is noted that the physical activity intervention designed to increase cardiorespiratory fitness significantly improved response accuracy in preadolescent children when performing a WM task. These results support the view that enhancing cardiorespiratory fitness could be an effective method to improve WM performance for children with DCD. However, although the cardiorespiratory fitness was also significantly enhanced in TD children, the accuracy rate was not improved in this study. The lack of consistency between the results of the present work and those of previous studies may be because the TD children in this study exhibited superior performance before training, which meant that they had less room to improve, owing to a ceiling effect.

The positive relationship between cardiorespiratory fitness and cognitive functioning in children has been reported in many previous neuroelectric studies using ERPs (Hillman et al., 2005, 2009; Kamijo et al., 2011; Pontifex et al., 2011). In terms of P3 activity, this component has been demonstrated to effectively reflect the relationship between cognition and cardiorespiratory fitness in children. For example, Hillman and colleagues (2005) adopted a stimulus discrimination task to investigate the relationship between cognitive function and aerobic fitness, and found that high-fitness children exhibited greater P3 amplitude compared with low-fitness children, suggesting that cardiorespiratory fitness is positively associated with neuroelectric indices of WM and attention in children. Children with DCD have been shown to have smaller P3 amplitudes than TD children when performing the endogenously arrow-cued and exogenously eye-gazed visuospatial orienting task (Tsai, Pan et al., 2009; Tsai et al., 2010; Tsai, Wang et al., 2012). Similarly, such a group also displayed smaller P3 amplitudes during the retrieval-process phase for later remembered items when performing the VSWM task in the current study. The P3 component is associated with the allocation of resources necessary for attention (e.g., stimulus evaluation) and memory processes (e.g., encoding, rehearsal, recognition, and retrieval) in the VSWM (Rugg, 1995). Children with DCD thus showed smaller P3 amplitudes in the 3s- and 6s-delayed
conditions during the retrieval-process phase, revealing that they allocated fewer resources for comparison of spatial locations, which might result in performing less accurately in the two time-delayed spatial memory tasks (Tsai, Chang et al., 2012). However, greater exercise-induced P3 amplitude was observed in the DCD-training group after the 16-week aerobic exercise intervention compared with those before training. Indeed, previous studies have demonstrated that higher fitness children, compared with lower-fitness children, show greater P3 amplitude when performing a stimulus discrimination task (i.e., a visual oddball paradigm) (Hillman et al., 2005) and a flanker task (Hillman et al., 2009; Pontifex et al., 2011), indicating that a larger population of neurons is recruited for performing the cognitive tasks in the former group when compared with the latter (Hillman et al., 2005). Increases in cardiorespiratory fitness could be beneficial to improve deficits in the VSWM of children with DCD in the present study, since they could allocate greater WM resources related to encoding and retrieval after the aerobic cardiovascular endurance training. Likewise, owing to the more physically active lifestyle in TD children relative to those with DCD (Rivilis et al., 2011), cardiorespiratory fitness was also enhanced in the former group in the current study, which resulted in greater P3 amplitudes during the encoding and retrieval-process phases. However, it is worth pointing out that Tsai, Wang and colleagues (2012) found that children with DCD only showed a beneficial effect with regard to P3 latency, and not P3 amplitude, after a 10-week period of soccer training compared with the pre-training values when performing a visuospatial attention task. The discrepant results could be attributed to the different exercise training modes and cognitive tasks in the two studies, since open-skill (e.g., soccer) and close-skill (e.g., running) exercises may have different effects on various forms of cognitive processing (Di Russo et al., 2010). Further investigations into these possibilities are needed to clarify this issue.

Following the P3 component, the pSW could reflect the retrieval of information from the WM and neural intermediate processes during the response selection or decision stages (i.e., the processing stage that establishes a specific response to a specific stimulus recognition) in choice reaction paradigms (Garcia-Larrea & Cezanne-Bert, 1998; Perchet & Garcia-Larrea, 2000). In agreement with the results shown in previous works (e.g., Tsai, Chang et al., 2012), the children with DCD in this study exhibited a smaller pSW amplitude, suggesting that they exerted less neural effort with regard to the retrieval and response selection. Additionally, the 16-week endurance training intervention did not lead to an improvement in the pSW amplitudes for the DCD-training group as a function of enhanced cardiorespiratory fitness, suggesting that the children with DCD could not derive any such benefits from their enhanced physical fitness. Since pSW is strongly related to the motor response (Perchet & Garcia-Larrea, 2000), this might account for the lack of improvement in the reaction time for the 3s- and 6s-delayed conditions in the DCD-training group following the endurance exercise intervention in the current study.

The right dorsolateral prefrontal cortex (DLPFC) and posterial parietal cortex are associated with cognitive control performance during WM tasks, and especially with the time-delayed elements (Crone, Wendelken, Donohue, Leijenhorst & Bunge, 2006). Specifically, the posterial parietal cortex has been shown to play a crucial role in successful achievement of the spatial delayed matching-to-sample tasks used in this study (Garcia-Larrea & Cezanne-Bert, 1998; Muller & Knight, 2002). From the neural developmental perspective, the frontal–parietal network is still immature in children aged 8–12 (Crone & Ridderinkhof, 2011). Therefore, to find out whether the improvements in WM performance seen across time are simply a developmental effect, both DCD nontraining and TD groups participated in the current study to minimize the potential bias and confounding factors. It has been suggested that children with DCD show some immaturity at the level of the posterial parietal cortex (Hyde & Wilson, 2010; Tsai, Pan et al., 2009; Tsai et al., 2010), with the findings of the current work showing that smaller P3 and pSW components were found in both DCD groups before exercise when performing the 3s- and 6s-delayed VSWM tasks, suggesting that the neural processing problems emerged during the memory and retrieval phases, supporting Allaway and colleagues (2009) view that children with DCD have problems in information processing and storage when performing a visuospatial memory task. Although the increased S2-evoked P3 amplitudes found in the TD group could be attributed to the developmental effect, this was also seen with the DCD-training group but not for the DCD nontraining group. Importantly, after the 16-week endurance exercise intervention, only the DCD-training group among the three groups exhibited a significantly enhanced performance in response accuracy, indicating that an exercise mode designed to increase cardiorespiratory fitness could be an effective way to improve the efficiency of the posterial parietal network in support of VSWM functioning in children with DCD.

In conclusion, the experimental data presented in this work offer evidence that a vigorous aerobic exercise program in an ecological setting (e.g., school) can improve the deficits of VSWM in children with DCD, which could be observed from the changes in their behavioral parameters (e.g., executive accuracy) and corresponding brain activation (e.g., P3 amplitude). Physical exercise appears to be a simple and widely practiced behavior that is able to achieve these neuropsychological and neurophysiological benefits. The potential mechanism underlying this could be that children with DCD can allocate greater WM resources related to encoding and retrieval when performing the VSWM task, since enhanced cardiorespiratory fitness has a beneficial effect on activating and adapting the neural processes involved in cognitive control (Chaddock et al., 2012). These results provided additional information with regard to the significance of a physically active lifestyle, especially for children with DCD who have a sedentary lifestyle and lower cardiorespiratory fitness (Rivilis et al., 2011).
There are limitations to this study which must be addressed. First, since the DCD nontraining and TD groups performed their regular classroom activities for the duration of this study, it is possible that the absence of a placebo intervention (e.g., a restriction on physical activity) for the TD and DCD nontraining groups may have resulted in a physical-activity-effect bias on the improvement of cognitive performance. Second, the endurance exercise intervention could have beneficial effects on academic, behavioral, and social functioning for the TD children, which could further affect their cognitive functioning (Castelli, Hillman, Buck, & Erwin, 2007), and limitations might exist with regard to understanding the effects of endurance training on the VSWM in the children with DCD, due to the lack of measurements regarding changes in these distal outcomes. Third, due to the gradually decreasing cardiorespiratory fitness following the end of the exercise intervention, this study could not examine how long the beneficial effects of physical activity are sustained in children with DCD. Future research efforts should thus address this issue, possibly examining the wash-out effects for such children with definite deficits with regard to having certain neural constraints (Sigmundsson, Whiting, & Ingvaldsen, 1999) and other neurological soft signs (Tsai et al., 2008).

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**Conflict of Interest**

None declared.

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**References**


