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Effects of exercise intervention on event-related potential and task performance indices of attention networks in children with developmental coordination disorder

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ABSTRACT

The study investigated whether 10-week soccer training can benefit the inhibitory control and neuroelectric indices in children with developmental coordination disorder (DCD). Fifty-one children were divided into groups of typically developing (TD, $n = 21$), DCD-training ($n = 16$), and DCD non-training ($n = 14$) individuals using the for Children test, and, before and after training, were assessed with the visuospatial attention orienting task with their lower extremities, while brain event-related potentials (ERPs) were concurrently recorded. The results indicated that, when compared to TD children, children with DCD responded significantly more slowly across conditions of the visuospatial attention orienting task and showed a deficit of inhibitory control capacity in their lower extremities, whereas no group differences were observed for the accuracy rate. Neuroelectric data indicated that, before training, P3 amplitude was smaller and P3 latency was slower for both DCD groups compared to TD children across conditions of the visuospatial attention orienting task; after training, the beneficial effects were seen in the strength of inhibitory control and P3 latency in the DCD-training group. The data suggest that soccer training resulted in significant improvements in ERP and task performance indices for the children with DCD.

1. Introduction

In the Diagnostic and Statistical Manual of Mental Health Disorder (DSM-IV), developmental coordination disorder (DCD) is a term describing motor impairment in the absence of specific neurological diseases, psychiatric problems, any known physical disorder, developmental delay, mental retardation, and low IQ (American Psychiatric Association, 1994). Notwithstanding the many experimental efforts currently being undertaken to identify the neuroanatomical bases of dysfunction that lead to motor control impairments exhibited by children with DCD as compared to typically developing (TD) children (e.g., Tsai, Pan, Cherng, & Wu, 2009b; Tsai, Wu, & Huang, 2008), the definite deficits that have been demonstrated are neural constraints (Sigmundsson, Ingvaldsen, & Whiting, 1997a; Sigmundsson, Ingvaldsen, & Whiting, 1997b; Sigmundsson, Whiting, & Ingvaldsen, 1999) and more neurological soft signs (Lundy-Ekman, Ivry, Keele, & Woollacott, 1991). Most importantly, the most pronounced mechanism in relation to cognitive processing in terms of distinguishing DCD and TD children has to with the strength of inhibitory control effect when performing the different versions of covert orienting of endogenous visuospatial attention tasks (e.g., the Posner paradigm) induced by arrow-directed cues with different stimulus onset asynchrony (SOA) (Tsai, 2009; Tsai, Pan, Cherng, Hsu, & Chiu, 2009a; Tsai, Yu, Chen, & Wu, 2009c; Wilson & Maruff, 1999; Wilson, Maruff, & McKenzie, 1997), and the exogenous visuospatial attention task induced by eye-gazed cues (Tsai, Pan, Chang, Wang, & Tseng, 2010). In addition, the possible neurological antecedents of DCD have been discussed in connection with intra and/or inter hemispheric functioning or dysfunctional corpus callosum formulated from the neurobehavioral models of inter- and intrasensory functioning (Sigmundsson et al., 1997a; Sigmundsson et al., 1997b; Sigmundsson et al., 1999) and the event-related potential (ERP) indices of the attention network (Tsai et al., 2009a; Tsai et al., 2010).

Attention, an essential neurobiological function, refers to a process by which we select stimuli in our environment for perception and action (Smith & Chatterjee, 2008). According to dual-process theories of attention (Corbetta & Shulman, 2002), orienting of attention is controlled by dorsal and ventral networks connecting the frontal and parietal lobes (Butler, Lawrence, Eskes, & Klein, 2009). Accordingly, lesions in parts of the middle and inferior frontal gyri and the parietal lobe have been implicated in impairment of covert orienting of attention and the capability of appropriate

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disengagement from a location to which attention is directed (Chambers & Mattingley, 2005; Posner, Walker, Friedrich, & Rafal, 1984; Snyder & Chatterjee, 2006).

Inhibitory control is an ability to ignore irrelevant input and/or withhold behavioral responses to either internal or external influences that are inappropriate in the current context (Fuster, 1997). Such a conflict resolution capability is a cognitive function (i.e., executive attention) which is important to engage in many everyday and athletic situations, such as operating a motor vehicle, riding a bicycle, and playing dodge ball or soccer, where it is often necessary to suddenly prevent ourselves from executing an inappropriately prepared action (Coxon, Stinear, & Byblow, 2007). Visuospatial attention, which is associated with the orienting network, provides a measure of conflict resolution (Posner, Rothbart, & Sheese, 2007), and can also be treated as valid and reliable index of an individual's inhibitory control capacity (Tsai, 2009; Tsai et al., 2009a; Tsai et al., 2010). Visuospatial attention shifts triggered by social cues, such as by the gaze shifts observed in another individual, along with the non-predictive gaze cuing effect (i.e., the probability of valid and invalid cuing is equal), have been recently adopted to explore the problem of inhibitory control in the ventral attention networks of DCD (Tsai et al., 2010). Indeed, children with DCD showed such a deficit when performing a task with gaze-triggered shifts of attention with their lower extremities (Tsai et al., 2010).

Attentional networks develop rapidly during early childhood. Substantial improvements in different functions of attention occur with separate developmental trajectories, such as the alerting network at age 9 years or beyond age 10, orienting network at or under age 6 years, error monitoring in 6–9 years, attentional disengagement in 7–9 years, inhibition control in 7–8 years or even during early childhood (Band, van der Volen, Overtoom, & Verbaten, 2000; Gupta & Kar, 2009; Rueda et al., 2004). Accordingly, the development of the attentional networks of children seems to reach adult levels by 9 years old. Most importantly, although attentional networks show rapid development during childhood, experiments carried out to examine the trainability of such cognitive functions in children have been shown to be generalized widely to other domains, such as inhibitory control (Diamond, Barnett, Thomas, & Munro, 2007; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). In addition, research has shown that the ecological setting (e.g., home and school) can exert an influence upon the cognitive networks responsible for executive attention and inhibitory conflict for developing children (Rueda et al., 2005).

Although the neural network underlying attention control is strongly related to typical maturation (Band et al., 2000; Gupta & Kar, 2009; Rueda et al., 2004), a hereditary attribute and substantially associated with the genetic influence (Blasi et al., 2005; Diamond, Brian, Fossella, & Gehlbach, 2004; Posner et al., 2007), and the inhibitory control function has also been shown to be highly heritable and associated with the dopamine-related genes (Fan, Wu, Fossella, & Posner, 2001; Klingberg, Forssberg, & Westerberg, 2002; Rueda et al., 2005), such an executive attention network can be facilitated by an easy attention training and inhibitory control exercise in front of a computer during typical childhood development, even with a very brief training period (Rueda et al., 2005). Children with DCD can also benefit from a group table tennis training intervention in an ecological setting, with their motor outcomes significantly enhanced as well as their inhibitory control deficit alleviated (Tsai, 2009). Therefore, the executive attention network is subject to educational intervention during development in typically developing children or children with DCD.

Exercise can serve as a means to benefit cognitive function, in that the behavior can activate molecular and cellular signaling cascades in various central nervous system processes (Stroth, Hille, Spitzer, & Reinhardt, 2009) and enhance the metabolism of important neurotransmitters, such as dopamine and serotonin (Meeusan, 2005), via an increase in regional blood flow in brain (Eggermont, Swaab, Luiten, & Scherder, 2006; Endres et al., 2003), upregulation of genes regarding cellular plasticity, and an increase in levels of brain-derived neurotrophic factors (Cotman & Berchtold, 2002). However, the robust and general improvements in cognitive function that accrue with physical exercise seem varying in size (Colcombe & Kramer, 2003), being larger for tasks requiring speed (simple reaction time), visuospatial and visual attention (Roth, Goode, Clay, & Ball, 2003; Shay & Roth, 1992), tasks requiring more extensive amounts of executive control (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009), and effortful processing requiring enhanced cognitive control, as compared to automatic processes (Chodzko-Zajao, Schuler, Solomon, Heinl, & Ellis, 1992). For children, physical exercise can facilitate specific aspects of their cognitive performance, and particularly executive function (i.e., processes required to select, organize, and properly initiate goal-directed actions) (Tomporowski, Davis, Miller, & Naglieri, 2008; Tomporowski, Lambourne, & Okumura, 2011).

Open-skill activities (e.g., soccer) require rapid shifts from broad to selective attention, and thus can modulate cognitive processing plasticity (e.g., P3 latency and amplitude) by the execution of physical exercise (Fontani, Maffei, Cameli, & Polidori, 1999; Iwadate, Mori, Ashizuka, Takayose, & Ozawe, 2005). In addition, soccer training is beneficial to the development of countermovement jumping, strength, and interlimb synchronization capabilities in children (Cortis et al., 2009), and leads to the formation of a motor complex integrating coordination, speed, agility, endurance, and explosiveness (Erceg, Zagorec, & Katic, 2008). Therefore, soccer training is a complex full-body coordination form of exercise which is recognized as involving an activation of the cerebellum which influences a variety of neurobehavioral systems, including attention (Courchesne et al., 1994) and working memory (Klingberg, Kawashima, & Roland, 1996), as well as motor functions. Indeed, the latent motor dimensions, especially in coordination and the speed of movement, show a positive and significant association with cognitive abilities for boys and girls (Planinsec, 2002).

As mentioned previously, children with DCD exhibited impaired inhibitory control in ventral attention networks (Tsai et al., 2010). However, exercise or high physical activity level can improve cognitive function (Hillman et al., 2009; Roth et al., 2003; Shay & Roth, 1992), and has beneficial effects on inhibitory control capability in children with DCD when performing the visuospatial attention task (Tsai, 2009). However, to date, no studies have been undertaken on the role of attention training using exercise intervention in pathologies, and no research has yet been conducted on the potential effects of soccer exercise intervention on the problem of inhibitory control in the ventral attention networks in children with DCD. Therefore, the main aim in the present work was to explore the effectiveness of soccer training with regard to improving the inhibitory control of children with DCD, while simultaneously considering the behavioral and electrophysiological performances when performing a visuospatial attention task with non-predictive eye-gazed directional cues. In addition, since relatively few studies have been conducted to examine the effects of chronic exercise on children's cognitive function (see reviews, Tomporowski et al., 2011), to the best of our knowledge, the present study provides the first electrophysiological evidence for the brain activity induced in children with DCD's by long-term exercise intervention. Based on the studies reviewed above, we hypothesized that soccer training would have a beneficial effect on the performance of a visuospatial attention task and improve the inhibitory control capability in children with DCD, and the potential mechanisms could be derived from different ERP changes, since the ERP can offer high temporal resolution with reasonable spatial resolution.