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The relationship between physical fitness and inhibitory ability in children with attention deficit hyperactivity disorder: An event-related potential study

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A B S T R A C T

Objectives: The purpose of the current study was to examine the relationship between physical fitness and interference control by comparing higher and lower fitness children with attention deficit hyperactivity disorder (ADHD) using event-related potentials (ERPs) and behavioral indices.
Design: Cross-sectional design was employed.
Method: Eighty children, previously diagnosed with ADHD, were evaluated on their inhibitory ability as measured during their participation in the flanker task, and this ability was examined in relationship to measures of their physical fitness. Only children in the top 40% or in the bottom 40% of the distribution for each fitness components were included in the statistical analysis.
Results: The results showed that children with higher levels of muscular endurance, muscular power, and aerobic capacity had shorter reaction times (RT) and larger P3 amplitudes compared to less fit children. In addition, children with lower body composition had shorter reaction times and shorter P3 latencies compared to those with higher body composition.
Conclusions: Better physical fitness, especially muscular endurance, muscular power, aerobic capacity, and body composition, were associated with enhanced interference control in children with ADHD. Our findings suggest the need for a closer examination of the possible impact of different aspects of fitness on the general relationship between physical fitness and cognition.

1. Introduction

Attention deficit hyperactivity disorder (ADHD), which typically first presents during the pre-school years, is the most common childhood developmental disorder, affecting 11% of school-aged children in 2011 (Visser et al., 2014). ADHD symptoms are characterized by inattention as well as hyperactivity and impulsivity (American Psychiatric Association, 2000). Cognitive deficits, poor academic performance, and impaired social functioning are frequently reported problems in children with ADHD (Gapin, Labban, & Etnier, 2011). Moreover, 70% of children with ADHD continue to display symptoms into adulthood (Faraone, Biederman, & Monuteaux, 2002). Although drug treatment for ADHD is effective, side effects often reduce its overall effectiveness (Wigal et al., 2006) and thus making it important to explore supplementary or alternative treatments for this disorder.

Poor inhibitory control is postulated as one of the core deficits of ADHD (Barkley, 1997). Several studies have reported that children with ADHD displayed longer reaction time and made more errors than control children in the flanker task, a measure of inhibitory control (Albrecht et al., 2008; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009).

In addition, research has found that children with ADHD showed a smaller P3 amplitude when in the incongruent condition of the flanker task i.e. where the target arrow was flanked by an

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opposing lateral arrow (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Such children also displayed longer latency in the central-parietal area under both congruent and incongruent conditions of the task (Jonkman et al., 1999). P3 component, which peaks between approximately 300 and 600 ms after stimulus onset, has been identified as the essential ERP component in the flanker task. The amplitude of P3 is sensitive to the allocation of attentional resources during stimulus engagement (Polich, 2007) whereas the peak latency of P3 is thought to indicate stimulus classification and evaluation speed independent of response selection and action (Verleger, 1997). This finding of smaller P3 amplitudes and longer latencies in children with ADHD therefore suggests an increase in stimulus processing and evaluation loads when these children are challenged with an interference control-demanding task.

Physical fitness has a positive impact on the neuro-physiological and cognitive processes commonly involved in ADHD. At the neuro-physiological level, long-term exercise increases the release and synthesis of several key neurotransmitters, such as dopamine and noradrenaline (Fulk et al., 2004), as well as neurotrophins, such as BDNF (Cotman & Berchtold, 2002), that play an important role in the pathophysiology of ADHD (Arnsten, 2006). At the cognitive level, higher physical fitness levels in children have been associated with better performance in a task that demanded various cognitive control abilities (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex, Scudder, Drollette, & Hillman, 2012). Although not unequivocal, there are indications that long-term participation in aerobic exercise may be beneficial to executive functions in children (Tomporowski, McCullick, Pendleton, & Pesce, 2015) and others (Hötting & Röder, 2013). Moreover, the beneficial effect of physical fitness or physical activity on cognitive performance has been extended to ADHD populations. For example, studies have shown that extended participation in exercise is associated with improvement in social, cognitive, and attentional problems as measured by the child behavior checklist (CBCL) (Verret, Guay, Berthiaume, Gardiner, & Beliveau, 2012), ADHD symptoms (Gapin & Etnier, 2014), as well as the planning (Gapin & Etnier, 2010) and inhibitory (Chang, Hung, Huang, Hatfield, & Hung, 2014) aspects of executive function in children with ADHD. Furthermore, children with ADHD with higher physical fitness (C. W. Huang, Huang, Hung, Shih, & Hung, 2015) or who participated in extended periods of aerobic fitness exercise (C. J. Huang et al., 2014) demonstrated more normal resting EEGs than their lower fitness counterparts. Although these studies have provided evidence for the beneficial effects of physical fitness and long-term physical activity on inhibitory control in ADHD populations, the complex nature of physical fitness require further investigation into the relationship between fitness and cognition.

Aspects of physical fitness, including cardiorespiratory fitness, muscular endurance, muscular power, and flexibility, have all been found to be positively related to cognitive function (Bass, Brown, Laurson, & Coleman, 2013; Stroth et al., 2009; Telles, Singh, Bhardwaj, Kumar, & Balkrishna, 2013). Among these components, cardiorespiratory fitness (i.e., aerobic capacity) has received particular attention. However, recent studies have called for more investigation into other fitness components. For example, it has been shown that, not only aerobic capacity, but also muscular endurance were positively associated with academic achievement in middle school (Bass et al., 2013). Similarly, Chomitz et al. (2009) found a positive correlation between the number of fitness tests passed and scores on both mathematic and English tests.

While the beneficial effects of physical fitness on cognitive function are well established, the reasons for this relationship are not fully understood and deserve further investigation.

Although no studies have directly examined the relationship between aspects of physical fitness and cognitive function in children with ADHD, some related investigations suggest the need for further work in this area. For example, Verret et al. (2012) found that a 10-week exercise program (involving playing basketball, soccer, and other ball games) not only improved fitness (as measured by the number of push ups performed) and gross motor skills but also information processing and sustained auditory attention in children with ADHD. Similarly, Pan et al. (2015) reported that children with ADHD participating in a 12-week (70 min twice per week) table tennis exercise program improved motor skills (e.g., locomotor and object-control skills) and performance on tasks involving executive function (i.e., WCST and Stroop) compared with both an ADHD and a non-ADHD control groups.

To the best of our knowledge, no research has specifically explored the relationship between fitness components and interference control at the neuro-electrical level in individuals with ADHD. Therefore, the current study aims to address this knowledge gap. We hypothesized that five fitness components (i.e., flexibility, muscular endurance, muscular power, aerobic capacity, & body composition) would be associated with performance in the flanker task. Specifically, it was hypothesized that children who were more fit would display shorter RTs, less error, larger P3 amplitudes, and shorter P3 latencies, compared with their less fit counterparts.

2. Methods

2.1. Participants

Eighty children participated in this study. All participants attended local elementary schools in Taipei, Taiwan, had been referred by special education teachers and parents over the period from May 2012 to December 2014, and had met all of the following inclusion criteria: (1) aged between 8 and 12 years; (2) diagnosed by a pediatric psychiatrist as having ADHD based on the text revised procedures of the fourth edition of the Diagnostic and Statistical Manual for Mental Disorders (DSM-IV-TR) (American Psychiatric Association, 2000); (3) free of co-morbid conditions, such as conduct/oppositional defiant disorder, autism spectrum disorders, or serious affective disorders; and (4) no history of brain injury or neurological conditions, such as epileptic seizures, serious head injuries, or periods of unconsciousness.

All children were administered form A of the Test of Nonverbal Intelligence (TONI-2), which is a language-free measure of cognitive ability. Test reliability has been found to increase with age, with internal test reliability varying from 0.81 to 0.98 (Konter, 2010), and test-retest reliability ranging between 0.80 and 0.95. Furthermore, test validity of the TONI-2, as defined by its correlation with general intelligence, has been estimated as being 0.80 (Brown, Shebenou, & Johnsen, 1990). The average of IQ across all participants was 99.66 ($SD = 15.04$).

Parents also provided details of their educational history and occupational status, and this information was used to compute separate educational and occupational measures of socioeconomic status (SES) based on Hollingshead's two-factor index. Where parents differed in their ratings on either of these two dimensions, the higher rating was recorded.

The Hollingshead measures have been shown to correlate highly with other measures of SES. For example, the occupational Hollingshead scale has been found to correlate 0.92 with an independently derived measure of SES based on census data published by the National Opinion Research Center (Hollingshead, 1975).

A new weighted composite measure, entitled the Index of Social Position (ISP), was then computed based on the following formula: ISP = (occupation score * 7) + (education score * 4) (Hollingshead, 1957). Five levels of socioeconomic status were defined according to the following categorization of ISP scores: 11–18, 19–29, 30–40,

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