Biological Psychology 110 (2015) 68–74

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Greater aerobic fitness is associated with more efficient inhibition of task-irrelevant information in preadolescent children

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ARTICLE INFO

Article history:
Received 13 February 2015
Received in revised form 9 July 2015
Accepted 13 July 2015
Available online 23 July 2015

Keywords:
Childhood fitness
Attentional orientation
P3a
Task-irrelevant information
Event-related brain potentials (ERPs)

ABSTRACT

A growing number of neuroelectric studies using event-related brain potentials have demonstrated that greater aerobic fitness is associated with superior cognitive functioning across the lifespan. However, empirical data regarding the association between fitness and attentional orienting is scarce, with no evidence in children, and the findings are inconclusive. We designed the present study to examine the relationship between aerobic fitness and involuntary attentional orientation to task-irrelevant information in preadolescent children. Lower-fit and higher-fit children performed a visual oddball task in which irregular (i.e., rule-violating) stimuli appeared as a task-irrelevant dimension, while measures of task performance and the P3a component elicited by the irregular stimuli were assessed. Analyses revealed that higher-fit children exhibited lower miss rates and smaller P3a amplitude relative to lower-fit children. These findings suggest that greater childhood fitness is associated with more efficient inhibition of task-irrelevant information.

1. Introduction

Accumulating evidence demonstrates that greater participation in physical activity and greater aerobic fitness, which is the ability to perform prolonged strenuous exercise (Ortega, Ruiz, Castillo, & Sjostrom, 2008), are associated with better cognitive functioning (Erickson, Hillman, & Kramer, 2015; Hillman, Erickson, & Kramer, 2008). Although the underlying mechanisms for the positive association of physical activity and fitness with cognitive functioning are still not confirmed, nonhuman animal models have indicated that aerobic training increases levels of key neurochemicals, such as brain-derived neurotrophin factor (BDNF) and insulin-like growth factor 1 (Carro, Trejo, Busiguina, & Torres-Aleman, 2001; Neeper, Gomez-Pinilla, Choi, & Cotman, 1995). These neurochemical changes promote synaptic plasticity and neurogenesis that support learning and memory (Lu & Chow, 1999; Praag, Christie, Sejnowski, & Gage, 1999). A randomized controlled study indicated that aerobic fitness training improved memory performance and increased hippocampal volume in older adults (Erickson et al., 2011). This study additionally indicated that greater increases in hippocampal volume were associated with greater increases in serum BDNF. Fitness has also been shown to be associated with better cognitive performance for processes such as attention and cognitive control (Erickson et al., 2015; Hillman et al., 2008). Researchers have begun to extend these findings to children. For example, a cross-sectional study indicated that higher-fit children exhibited better memory performance and greater hippocampal volume relative to lower-fit children (Chaddock et al., 2010). These findings are consistent with the findings in older adults, and imply that the positive association of physical activity and fitness with cognitive functioning may be similar across the lifespan.

Hillman, Castelli, and Buck (2005) found that greater aerobic fitness is associated with superior cognitive functioning in preadolescent children using the P3b (also known as the P3 or P300) component of event-related brain potentials (ERPs). Neuroelectric studies have played a critical role in examining this association in children (for reviews see Hillman, Kamijo, & Pontifex, 2012; Kamijo, in press). The P3b, which is a positive ERP component occurring approximately 300-800 ms after stimulus onset, has been extensively used in such studies. These ERP studies have demonstrated that greater aerobic fitness, measured by the 20-m shuttle run test or maximal oxygen uptake, is associated with larger P3b amplitude as well as shorter reaction times (RTs) and/or greater response accuracy in preadolescent children (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Hillman et al., 2005; Pontifex et al., 2011). The amplitude of this component has been considered to

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http://dx.doi.org/10.1016/j.biopsycho.2015.07.007
0301-0511/

reflect the amount of attentional resources deployed during stimulus engagement (Polich, 2007). Accordingly, these ERP studies suggest that higher-fit children can recruit a greater amount of attentional resources to target stimuli to make quicker and/or more accurate responses.

A few adult studies (Getzmann, Falkenstein, & Gajewski, 2013; Pontifex, Hillman, & Polich, 2009) examined the association between fitness and cognitive function using another subcomponent of the P3, the so-called P3a, which reflects cognitive processes distinct from those captured using the P3b. Pontifex et al. (2009) compared lower-fit and higher-fit younger and older adults' task performance and the P3a during a visual three-stimulus oddball task. This task required participants to respond to rare target stimuli (a 55 mm diameter circle; 12% frequency), which elicited the P3b component, and to withhold their responses to frequent standard stimuli (a 50 mm diameter circle; 76%) and rare and salient distractor stimuli (a full-screen checker board; 12%), which elicited the P3a component. The P3a component has a more frontal topographical distribution and shorter peak latency relative to the P3b component. It is believed to reflect involuntary attentional orientation to task-irrelevant information with increased amplitude related to greater engagement of focal attention (Polich, 2007; Soltani & Knight, 2000). Pontifex et al. (2009) indicated that lower-fit and higher-fit individuals exhibited comparable task performance and P3a amplitude, suggesting that fitness is not associated with involuntary attentional orienting.

In contrast, Getzmann et al. (2013) found that fitness was associated with P3a amplitude. They used an auditory duration discrimination task composed of frequent standard stimuli (1000-Hz tone; 80% frequency) and rare deviant stimuli (500-Hz and 2000-Hz tones; each 10%), such that half of these stimuli had short durations (200 ms) and the other half had long durations (400 ms). Participants were asked to press one of two buttons corresponding to the duration of the tones irrespective of the tone pitch. They found that higher-fit older adults had a smaller difference in RT between the deviant and standard stimuli and smaller P3a amplitude, relative to their lower-fit peers. These findings suggest that higher-fit individuals conserve limited resources for suppressing task-irrelevant information (i.e., tone pitch) to adequately detect target stimuli or to focus on task-relevant information (i.e., tone duration). Thus, empirical data regarding the association between fitness and involuntary attentional orienting is scarce, with no evidence in children, and the findings remain inconclusive.

We designed the present study to examine the relationship between aerobic fitness and involuntary attentional orientation to task-irrelevant information in preadolescent children. We compared lower-fit and higher-fit children's task performance along with their P3a during a visual rotation oddball task in which irregular (i.e., rule violating) stimuli appeared as a task-irrelevant dimension (cf. Kimura & Takeda, 2015). To our knowledge, only two ERP studies have examined the association between fitness and involuntary attentional orienting (Getzmann et al., 2013; Pontifex et al., 2009). Although the cognitive tasks used in these ERP studies differed mostly in terms of stimulus modality and response requirements, P3a can be elicited by infrequent task-irrelevant deviant stimuli. Because the deviant stimuli used in Pontifex et al. (2009) were extremely salient (i.e., a full-screen checker board), it is possible that the association between aerobic fitness and P3a was weakened (i.e., a ceiling effect). Thus, in the present study, we used a rotation oddball task, in which the intensity of the irregular stimuli was equivalent to the regular stimuli and appeared as a task-irrelevant dimension. In Getzmann et al. (2013), the P3b component was elicited irrespective of the stimulus type during a two-alternative forced-choice task, in which all of the trials required a response by pressing one of two buttons. To avoid a superimposition of the P3b on the P3a component, the current oddball task was designed not to elicit the P3b component for regular and irregular stimuli, which did not require a response. In addition, since most studies that examined the association between childhood fitness and cognitive functioning have been used the visual modality (Hillman et al., 2012; Kamijo, in press), we employed a visual oddball task in this study.

We predicted that if greater childhood fitness is associated with more efficient inhibition of task-irrelevant information as observed in older adults (Getzmann et al., 2013), then higher-fit children would exhibit a lower false alarm rate and smaller P3a amplitude relative to their lower-fit peers. Concurrently, according to the findings of Pontifex et al. (2009), it would also be possible to find no differences in false alarm rates and P3a amplitude between lower-fit and higher-fit children. Lastly, based on previous ERP studies using the P3b component for target stimulus processing (Hillman et al., 2009; Hillman et al., 2005; Pontifex et al., 2011), we predicted that higher-fit children would exhibit shorter RTs, lower miss rates, and larger P3b amplitude relative to lower-fit children.

2. Method

2.1. Participants

To recruit participants, we promoted the current study through elementary schools in Kanoya city (southwest Japan). The schools provided a list of children who were interested in participating in this study and whose legal guardians had given written informed consent. The schools also provided information about the children's scores on the 20-m shuttle run test, which was performed at each participant's school at the beginning of the academic year (approximately four months before the current experiment). The eligible participants were qualified as lower-fit and higher-fit children based on whether their 20-m shuttle run scores fell below the 30th percentile (i.e., lower-fit) or above the 70th percentile (i.e., higher-fit) normative data provided by the Japanese Ministry of Education, Culture, Sports, Science and Technology (2013). Children who did not qualify as lower-fit or higher-fit were excluded from further participation.

The 20-m shuttle run test was performed according to the protocol of Leger, Mercier, Gadoury, and Lambert (1988). Participants were instructed to run back and forth between two lines 20 m apart. They were paced by a tone on a CD player signaling when they needed to reach the opposite line. The initial speed was set at 8.5 km/h with the speed increasing by 0.5 km/h every minute until the test ended. This ending was signaled by a participant's failure to reach the end lines in the allotted time on two consecutive occasions. The total number of laps was recorded. We calculated the age- and sex-specific percentile scores as an index of aerobic fitness based on normative data provided by the Japanese Ministry of Education, Culture, Sports, Science and Technology (2013) in order to exclude age- and sex-related differences.

Prior to testing, the legal guardians reported that their child was free of neurological diseases, attention disorders (≤80th percentile on the ADHD Rating Scale IV; DuPaul, Power, Anastopoulos, & Reid, 1998), or physical disabilities, and had normal or corrected-to-normal vision. Following this screening, a total of 18 lower-fit and 20 higher-fit children participated in this study. Table 1 provides the participants' demographic and fitness information. No underweight or obese children, as defined by the national cutoff points (Japanese Ministry of Education, Culture, Sports, Science and Technology, 1981–2002), were included in this sample. The demographic measures, except for the fitness measures, did not differ between groups, *ts* (36) $\leq$1.8, *ps* $\geq$.08. All participants and their legal guardians provided written informed consent in accordance