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Cardiovascular fitness and executive control during task-switching: An ERP study

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ABSTRACT

Cardiovascular fitness recently has been linked to executive control function in older adults. The present study examined the relationship between cardiovascular fitness and executive control in young adults using event-related potentials (ERPs). Participants completed a two-part experiment. In part one, a graded exercise test (GXT) was administered using a cycle ergometer to obtain VO_2max, a measure of maximal oxygen uptake. High-fit participants had VO_2max measures at or above the 70th percentile based on age and sex, and low-fit participants had VO_2max measures at or below the 30th percentile. In part two, a task-switching paradigm was used to investigate executive control. Task-switching trials produced slower response times and greater amplitude for both the P3a and P3b components of the ERP relative to a non-switch trial block. No ERP components varied as a function of fitness group. These findings, combined with results from previous research, suggest that the relationship between greater cardiovascular fitness and better cognitive function emerges after early adulthood.

“Exercise does more than build muscles and prevent heart disease. New science shows that it also boosts brainpower.” (Carmichael, 2007, p. 38) This statement from a recent issue of *Newsweek* boldly promoted exercise as an activity that is beneficial for cognitive function. Indeed, there is ample evidence from meta-analyses for a positive correlation between physical activity and cognitive performance on a wide variety of measures (Colcombe and Kramer, 2003; Etnier et al., 2006, 1997), but the relationship between physical fitness and cognition in young adult populations has yet to be thoroughly investigated (Etnier et al., 2006). As a result, the present study examined the question, is cardiovascular fitness positively correlated with enhanced cognitive ability in young adults?

Research exploring the relationship between physical fitness and cognition has examined a particular form of cognition known as executive control. Executive control, a function managed primarily by the prefrontal cortex (Banich, 2004), is a form of higher-order processing that involves the selection of the correct action in response to an external stimulus that allows multiple, conflicting actions (Norman and Shallice, 1986). A variety of cognitive tasks have been developed to test executive control function including the Eriksen flanker task which asks participants to respond to a stimulus surrounded by neutral or distracting symbols (Eriksen and Eriksen, 1974), and task-switching paradigms which involve switching between at least two tasks while keeping those task sets active in working memory and inhibiting competing tasks (Monsell, 2003; Rogers and Monsell, 1995). In older adult populations (55–80 years), physically fit individuals performed better than sedentary individuals on tasks requiring executive control (Colcombe and Kramer, 2003).

In order to determine whether fitness levels are associated with changes in cognition and neural activity, the link between high levels of cardiovascular fitness and improved executive control has been investigated using event-related potentials (ERPs). Standard executive control tasks (Eriksen flanker task and task-switching paradigms), along with visual and auditory oddball tasks which require participants to respond to an infrequent target stimulus, elicit the P3 component of the ERP. P3 is a positive-going waveform with about a 300 ms latency that is generated when participants attend to and discriminate between differing stimuli, and its amplitude and latency are commonly used to assess cognitive function (Polich and Kok, 1995). P3 amplitude reflects the amount of attentional resources allocated in response to a stimulus, and P3 latency reflects speed of response to a stimulus. Therefore, greater amplitude and shorter latency indicate superior cognitive performance. More recently, the P3 has been separated into two components: P3a and P3b (Polich, 2003). P3a is elicited in response to a novel or infrequent stimulus, is prominent at frontal and central electrode sites, has short peak latency (250–300 ms), and is believed to reflect frontal lobe attentional processes. P3b is prominent at central and parietal electrode sites, peaks later than the P3a (300–525 ms), and may indicate that attentional resources are being allocated for subsequent memory updating.

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By examining differences in P3 activity between fitness groups, previous studies utilizing visual oddball tasks (Dustman et al., 1990; McDowell et al., 2003) and an Eriksen flankers task (Hillman et al., 2004) have provided mixed evidence for more efficient neurological functioning in fit, older adult participants ranging from 54 to 70 years old. When analyzing P3 amplitude, high-fit and moderate-fit older adults had greater P3 amplitude than young adult controls (M=20.4 years) at the Fz site, and low-fit older adults had decreased P3 amplitude than young adults at the CPz site (Hillman et al., 2004). Conversely, no P3 amplitude differences were found between fitness groups (Dustman et al., 1990), and the P3 area under the curve (AUC) was greater for low-fit older adults than high-fit older adults (McDowell et al., 2003). McDowell et al. concluded that a smaller AUC for high-fit groups suggests better attentional processing, which is inconsistent with the hypothesis that greater P3 amplitude reflects more efficient processing (Polich and Kok, 1995). When P3 latency was evaluated, high-fit older men had shorter P3 latency as compared with low-fit older men (Dustman et al., 1990), and high-fit older adults and young adults had shorter P3 latency than moderate-fit and low-fit older adults (Hillman et al., 2004). However, McDowell et al. found no P3 latency differences between fitness groups. In addition to the inconsistent P3 amplitude and latency effects among studies, the lack of distinction between P3a and P3b makes it more difficult to come to a clear conclusion. Combining P3a and P3b may have blurred two unique aspects of cognitive function together. For example, separate analyses of the two components may reveal that fitness is more strongly related to frontal lobe attentional processes (P3a) than memory updating (P3b), or vice versa.

Because the general fitness and cognition literature is ambiguous, the relationship between cardiovascular fitness and cognitive functioning in young adults, reflected in ERP components, is also unclear. In response to visual and auditory oddball paradigms, high-fit young adults have exhibited greater P3 amplitude (Polich and Lardon, 1997) and shown no P3 differences (Dustman et al., 1990; Magnié et al., 2000; McDowell et al., 2003). In a recent study of fitness effects on executive control using task-switching, Hillman et al. (2006) measured ERPs in four groups of participants: older active, older sedentary, younger active, and younger sedentary. Participants made greater than/less than or odd/even judgments in response to digits. In two blocks, the same task was repeated, whereas another block required them to switch between the two tasks. Faster reaction times (RTs) and greater accuracy were observed for the non-switch blocks versus the switch block. This indicated that switching between the two tasks may have been more challenging than repeating the same task, which replicates previous task-switching behavioral results (Rogers and Monsell, 1995). Task-switching was correlated with longer P3 latency but smaller P3 amplitude. In order to analyze fitness effects, participants were collapsed into active and sedentary groups regardless of age. During switch blocks, physically active participants had faster RTs, greater P3 amplitude at central and parietal sites, and shorter P3 latency at central and parietal sites. Because these fitness effects were not separated by age group, it is unclear whether fitness is associated with executive control improvements in young adults. In addition, P3a and P3b components were not examined in the ERP analysis, which limits the specificity of the ERP results.

Several possible explanations may account for the null or inconclusive results found when studying young adults. First, the ages of young adults tested varied across studies. Polich and Lardon's (1997) high- and low-fit young adult groups had a mean age of 30.0 and 34.7 years, while Dustman et al. (1990), Hillman et al. (2006), Magnié et al. (2000), and McDowell et al. (2003) tested adults ranging from 19.4 to 26.3 years of age. This may introduce potentially confounding variables such as age differences in cognitive function and might make it difficult to effectively assess cardiovascular fitness level using age-sensitive measures. Second, various self-report measures were used to assess individual fitness and assign participants to comparison groups (Hillman et al., 2006; Magnié et al., 2000; McDowell et al., 2003; Polich and Lardon, 1997) rather than using VO_2max to assess cardiovascular fitness.[1] VO_2max is an accurate physiological measure of maximal oxygen uptake (American College of Sports Medicine (ACSM), 2006), and a higher VO_2max indicates greater cardiovascular fitness (Montoye et al., 1996). VO_2max is a preferred measure of fitness because self-reports might be influenced by social desirability bias (Adams et al., 2005), and the wide variation in self-report measures makes comparisons across studies problematic. Third, the oddball and executive control tasks used in the previous studies may not have been overly challenging for young adults. Past ERP studies involving task-switching have reported greater P390 amplitude for switch versus non-switch trials at parietal sites (Moulden et al., 1998), increased late (400–920 ms) positive ERP amplitude for switch trials over frontal and central electrode sites (Rushworth et al., 2002), and greater early (200–300 ms) positive ERP amplitude for switch trials (Karayanidis et al., 2003). In contrast, Hillman et al.'s (2006) task-switching paradigm elicited greater P3 amplitude for non-switch versus switch trials. This finding may reflect initial attention devoted to the non-switch trials and suggests the subsequent switch task was somewhat automatic and not sufficiently demanding.

In order to clarify the relationship between fitness and cognition, the first purpose of the present study was to evaluate the effect of cardiovascular fitness on task-switching exclusively in a young adult population. Young adults 18 to 28 years old were tested based on the ACSM's (2006) young adult group for VO_2max percentiles. We aimed to improve upon overall fitness measures by assessing VO_2max for each individual in order to create high- and low-fitness groups. It was our hypothesis that if executive control functioning is affected by cardiovascular fitness levels, then high-fit participants would exhibit greater accuracy, faster RTs, and greater P3 amplitude on switch trials than low-fit participants.

A second purpose of the present study was to use a more challenging task-switching paradigm that would elicit P3 differences between switch and non-switch trials in young adults. In a previous comparison of task-switching difficulty, RTs were longer, accuracy decreased, and P3 amplitude was marginally larger at Cz and Pz for switch trials in a three-task condition compared to a two-task condition (Barcelo et al., 2006). The authors concluded that the three-task condition required the participants to keep more information active in working memory, and the greater response uncertainty when switching between three tasks contributed to the P3 differences. As a result, the present switch task required switching between four different numerical tasks in order to increase cognitive load. Additionally, the task tested executive control processes by requiring the selection of the correct task from four possible tasks (Norman and Shallice, 1986), keeping all four tasks active in working memory, and inhibiting competing tasks (Rogers and Monsell, 1995). The present switch task was hypothesized to result in slower RTs, less accuracy, and greater P3 amplitude for switch trials compared to non-switch trials (Barcelo et al., 2006).

[1] Although Hillman et al. (2006), Magnié et al. (2000), McDowell et al. (2003), and Polich and Lardon (1997) did not use VO_2max to assign participants to comparison groups, Dustman et al. (1990) established fitness groups based on VO_2max. In addition, McDowell et al. (2003) reported that VO_2max correlated with their participants' self-reports of physical activity. These self-reports were used to group participants by fitness level.