2008

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Recommended Citation

Mraz '08, Elizabeth K., "The Effects of Cardiorespiratory Fitness on Behavioral and Neuroelectric Indices of Cognition in Young Adults" (2008). *Honors Projects*. 120.
https://digitalcommons.iwu.edu/psych_honproj/120

Running Head: FITNESS AND COGNITION

The Effects of Cardiorespiratory Fitness on Behavioral and Neuroelectric Indices of Cognition in Young Adults

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Abstract

Effects of cardiorespiratory fitness on cognition were assessed for 72 young adults. Participants completed an executive control task while behavioral and neuroelectric indices of cognition were obtained. Behavioral (reaction time, response accuracy) and neuroelectric (P3 amplitude, P3 latency) measures of cognitive function and processing were examined in relation to fitness to determine the unique influence of fitness on cognition. A graded maximal exercise test was used to measure fitness by assessing maximal oxygen consumption. Higher fitness was associated with a smaller difference in P3 amplitude across expectancies as well as a longer P3 latency at the central midline site, suggesting a relationship between fitness and neural indices of certain cognitive processes. However, fitness did not exhibit a unique relationship with behavioral indices of cognition. These findings suggest that while fitness may have beneficial effects on some executive control functions, these effects may not be manifest in improved expectancy effects in the behavior of healthy young adults.

The Effects of Cardiorespiratory Fitness on Behavioral and Neuroelectric Indices of Cognition in Young Adults

Cardiorespiratory fitness arising from a long-term commitment to physical exercise has been shown to produce beneficial effects in terms of physical health, disease prevention, and mental health (Anderson, Missari, Kain, & Webster, 2006; Biddle & Mutrie, 2001; Erickson et al., 2007; Mead et al., 2007). A benefit of long-term fitness that has only recently appeared in the literature, however, is improvement in cognitive abilities (Colcombe & Kramer, 2003). This finding may have important implications for college students desiring to maximize their academic performance through involvement in an exercise program, or older adults aspiring to counteract the decline in cognitive abilities due to aging. Cardiorespiratory fitness has been demonstrated to have positive effects on cognitive functioning, specifically on tasks utilizing executive control (Hillman, Kramer, Belopolsky, & Smith, 2006a; Kramer et al., 1999). Enhanced fitness may allow people to more efficiently allocate attention toward a mental task and more thoroughly update mental processes during a cognitive enterprise (Colcombe et al., 2004).

The specific ways by which fitness affects cognition are yet to be established, and researchers are continuing to examine various facets of fitness and cognition in an attempt to pinpoint the mechanisms involved. Developing a deeper understanding of the benefits of fitness for cognitive functioning may provide important implications for improving cognitive vitality by adopting a more active lifestyle. Many aspects of mental functioning are out of one's control and are highly dependent upon biology, the environment (Oliver, 2007), and natural aging processes (Raz, 2000). However, the idea that people may be able to maintain their own cognitive functioning by making simple, inexpensive, and accessible changes to their lifestyle is a meaningful discovery, especially during an era in which people are living longer and diseases that inhibit mental functioning, such as Alzheimer's disease, are becoming more prevalent. Additional support for the positive relationship between cardiorespiratory fitness and cognitive functioning may also supply motivation for people to invest more time into exercising and being active.

In the field of cognitive neuroscience, researchers have studied a variety of executive control processes and their effects on task performance. One process involves adjustments in behavior due to participants' expectancies of a task, which are based on information from the previous trial of the task (Gratton, Coles, & Donchin, 1992). These expectancy effects are evident in real-life situations such as students' preparedness for an exam after previously completing difficult assignments, employees' readiness to deal with demanding customers based on previous customers' behavior, or people's ability to control their vehicles in the winter depending on prior road conditions. Success in each of these endeavors depends upon previous experiences and expectations, and understanding the effects of expectancies on cognitive performance is applicable to all people who are faced with problem solving tasks. Although expectancy effects are related to executive control in that they involve higher-level mental operations (Gratton et al., 1992), and fitness is thought to contribute to executive control (Kramer et al., 1999), the interaction between fitness and expectancy effects on a cognitive task has yet to be explored.

The current study provides further insight into the effects of fitness on cognition in young adults by analyzing the effects of fitness on the reaction time and accuracy on a difficult cognitive task and the amount of attention allocated during the performance of the task. Additionally, the current study illuminates the interaction between increased cardiorespiratory fitness and expectancy effects on the performance of subsequent trials of a cognitive task. Before detailing the current study, the existing literature regarding the effects of fitness on cognitive performance and neuroelectric activity will be explored. The questions that still remain in regard to the effects of fitness on cognition will be identified, and the current study will attempt to address these unresolved issues.

Defining and Measuring Fitness

Researchers have studied fitness using a wide array of approaches. Some studies have measured the effect of acute bouts of exercise on cognitive functioning (Hillman, Snook, & Jerome, 2003), while others have focused on the influence of continued exercise over longer periods of time on cognition (Colcombe et al., 2004). Various methods have been applied to measure physical fitness. Several studies have estimated fitness, using measures such as the Yale Physical Activity Survey (YPAS; Dipietro, Caspersen, Ostfeld, & Nadel, 1993), which measures total energy expenditure during an average week in terms of kilocalories burned (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Hillman et al., 2006a; Themanson, Hillman, & Curtin, 2006). This measure requires researchers to deduce cardiorespiratory fitness based on physical activity. A different measure of fitness is acquired through a self-report survey about lifestyle and health (Hillman et al., 2006b). This measure also requires the calculation of fitness from other variables and is subject to social desirability bias (Shaughnessy, Zechmesiter, & Zechmeister, 2006). Researchers have also utilized field tests to measure fitness, specifically the *Fitnessgram* (Cooper Institute for Aerobic Research, 2004), which estimates aerobic capacity, muscle strength, flexibility, and body composition using a series of drills and measurements (Hillman, Castelli, & Buck, 2005). The most precise measure of cardiorespiratory fitness is the graded maximal exercise test (GXT), which measures maximal oxygen uptake ($V0_{2max}$). This is the only method for obtaining a true measure of aerobic capacity without necessitating the calculation of fitness from other variables.

Researchers have frequently grouped participants based on level of fitness (Hillman et al., 2004; Hillman et al., 2005; Themanson & Hillman, 2006), or based on whether they live an active or sedentary lifestyle (Hillman et al., 2006a). Other researchers have suggested that grouping participants by fitness level creates arbitrary groups and may lead subtle individual differences to be overlooked or important information to be excluded (Themanson et al., 2006). These researchers recommend instead that fitness be analyzed as a continuous variable (Themanson et al., 2006). Another benefit of viewing fitness as a continuous variable instead of a grouping variable is the ability to use a participant pool with varying levels of fitness instead of having to recruit participants from extreme groups. When studying the differences between highly fit individuals and people with low cardiorespiratory fitness, researchers often have to recruit participants known to have very high or very low fitness, such as professional athletes or sedentary older adults, in order to detect differences between groups; this specificity in recruitment is not necessary when studying a spectrum of fitness levels. Furthermore, analyzing fitness as a continuous variable may allow for a greater degree of external validity due to the fact that cardiorespiratory fitness exists on a continuum naturally.

The current study adds to previous fitness-related research in the field by treating fitness as a continuous variable, utilizing the GXT to measure cardiorespiratory fitness, and focusing on fitness resulting from habitual aerobic exercise as opposed to short bouts of physical exertion. This study expands upon previous studies by attempting to discover the effects of cardiorespiratory fitness on performance of tasks involving higher-order cognitive functions collectively known as executive control, focusing specifically on interference control, which involves ignoring irrelevant information while focusing on the target stimulus, and expectancy effects, or using information from previous experiences to complete a task.

Behavioral Indices of Cognition

Fitness has been found to have beneficial effects on the performance of cognitive tasks, especially those that involve higher-order processes (Colcombe & Kramer, 2003; Themanson et al., 2006) such as interference control (Kramer et al., 1999; Hillman et al., 2006b), effortlessly switching between tasks (Kramer et al., 1999), and keeping more than one set of information available and accessible through working memory (Hillman et al., 2006a). These types of processes are collectively known as *executive control* and are not automatized over time (Colcombe & Kramer, 2003; Hillman et al., 2004), but instead require conscious effort (Hillman et al., 2003) and constant governing by a control center in the brain (Colcombe & Kramer, 2003).

A cognitive task that has frequently been utilized in fitness studies is the Eriksen flanker task (Eriksen & Eriksen, 1974), which assesses one aspect of executive control called *interference control*, or focusing on the task while ignoring irrelevant, interfering stimuli. In the task, participants are required to focus attention on a stimulus in the center of the field of view while ignoring distractors, or flanking stimuli (Hillman et al., 2004). Colcombe and Kramer (2003) explain that the task necessitates that participants suppress conflicting information surrounding the target stimulus and focus only on the central (target) stimulus. A variable amount of interference control is required across task conditions to successfully complete the task as instructed. In the *congruent* or compatible condition, flanking stimuli match the target stimulus (<<<<< or >>>>>). The other condition is designated the *incongruent* or incompatible condition because flanking stimuli provide different information than the target stimulus (<<><< or >><>>). Incongruent trials are associated with longer reaction times and a greater number of errors than congruent trials.

Themanson and Hillman (2006) explain that incongruent trials require increased executive control in the form of interference control when compared with congruent trials because the activation of the correct response, prompted by the stimulus in the center of the field, is in conflict with the simultaneous activation of the incorrect response, which is triggered by flanking stimuli. The validity of this measure is supported by the fact that performance on the flanker task decreases due to declining cognitive abilities associated with aging (Hillman et al., 2006b). Since fitness has been shown to play a specific role in cognitive performance of difficult tasks (Hillman et al., 2003), it may have the greatest effect on performance on incongruent trials of the flanker task.

Fitness Effects on Executive Control Functions

The majority of researchers in the field have concluded that increased physical fitness has positive effects on performance of cognitive tasks that require executive control. Hillman et al. (2006a) found that people who live a more active lifestyle responded, on average, more quickly on a cognitive task than people who live a sedentary lifestyle. Other researchers have found that people who participated in more frequent physical activity respond more quickly on the flanker task than people who exercised less frequently, and, for a group of older adults (mean age 49.6), more frequent physical activity corresponded to improved accuracy on the flanker task (Hillman et al., 2006b).

Using an experimental design, Kramer and colleagues (1999) concluded that people who participated in an aerobic exercise program for six months showed significant improvements in cognitive performance. Specifically, a group of adults who were randomly assigned to an aerobic walking program improved in switching quickly between cognitive tasks, showed increased ability to ignore task-irrelevant stimuli, and reduced the time it took them to abort a preplanned action on a cognitive task, while the control group that did not participate in the fitness walking program did not demonstrate these improvements (Kramer et al., 1999).

Adding to these results, Colcombe et al. (2004) conducted two separate experiments, concluding in both that increased cardiovascular fitness or participation in an aerobic training program predicted better performance on a cognitive task. Specifically, high-fit participants (according to the results of a one-mile walk test) in the cross-sectional experiment demonstrated better ability to deal with conflicting information in the flanker task, computed as a percentage increase in reaction time due to increased interference, compared to low-fit people. In their longitudinal experiment, participants who engaged in an aerobic exercise program for six months significantly improved their ability to deal with conflicting cues on the flanker task, while participants in the control group showed a minor improvement that was not statistically significant (Colcombe et al., 2004).

Fitness also appears to benefit executive control functions other than interference control. For example, Themanson and Hillman (2006) examined action monitoring, which addresses one's ability to detect and correct one's own errors. They found that higher-fit individuals, measured using a GXT, demonstrated significantly better performance (faster reaction time) following error trials of a cognitive task than did lower-fit individuals, suggesting that increased fitness is related to greater top-down executive control functioning (Themanson & Hillman, 2006). Furthermore, the higher-fit group showed a significant differentiation in reaction time on correct trials following error trials than on correct trials following correct-matched trials, while the lower-fit group did not. The researchers suggested that higher-fit individuals recruit and implement greater attentional control of cognitive behaviors following error commission than lower-fit people (Themanson & Hillman, 2006). A similar study demonstrated that more physically fit individuals showed increased post-error response slowing than less physically fit individuals, showing that higher fitness is associated with increased abilities to detect and correct errors during a task (Themanson et al., 2006). The current study attempted to expand upon these conclusions by determining specific executive control tasks in which cardiorespiratory fitness has the most beneficial effect.

Contrary Evidence

Though most published studies demonstrate a benefit of increased fitness on cognition, other researchers disagree with this conclusion. In a review of 27 studies of the effects of exercise on cognition, Tomporowski and Ellis (1986) did not reach a consensus because of a disagreement in methodology between studies and the fact that the results of many studies were influenced by motivational factors or physiological effects of exercise. Similarly, Etnier, Nowell, Landers, and Sibley (2006) concluded in their meta-analysis that variables such as age, health status, method of measuring fitness, and cognitive test category mediate the effect of physical fitness on cognitive performance. However, they stipulated that aerobic fitness may be a crucial initial step toward behaviors that directly benefit cognition. One possible explanation for why some meta-analyses did not confirm the beneficial effects of fitness for cognition is that these analyses included studies that did not necessarily focus on executive control functions. Researchers suggest that fitness has the most noticeable effects on executive control processes (Colcombe & Kramer, 2003).

An earlier meta-analysis by Etnier and colleagues (1997) concluded that studies involving chronic exercise had significantly greater effect sizes (ES = 0.33) than those involving acute exercise (ES = 0.16), suggesting that exercise has more beneficial effects on brain functioning when it is part of a person's lifestyle or implemented as a chronic prescription than when it is performed in brief intervals. However, they also concluded that, overall, the effect size for fitness was small (ES = 0.29), suggesting that many other variables (such as education or socioeconomic status) account for variance in cognition besides physical fitness. The variability in conclusions of meta-analyses may be the result of disparate assessments of fitness and variety in the cognitive tasks utilized. For example, in a meta-analysis of 18 studies, Colcombe and Kramer (2003) demonstrated that, overall, bouts of exercise with a duration of less than 30 minutes did not have a large impact on cognitive abilities. The present study examined cardiorespiratory fitness resulting from long-term commitment to physical activity as opposed to short bursts of exercise and utilized a commonly-used interference control task, which may allow researchers to better understand the specific situations in which fitness affects cognition and resolve the confusion over whether or not fitness is an important factor for cognitive functioning. The present study focused on cognitive performance on more difficult items of the flanker task and the effects of switching between congruent and incongruent trials, which triggers higher-order executive control processes, specifically interference control, and may therefore demonstrate more pronounced effects of fitness (Colcombe & Kramer, 2003; Hillman et al., 2006b; Kramer et al., 1999).

Expectancy Effects on Behavioral Indices of Cognition

One specific aspect of cognitive performance that has been assessed by researchers is the effect of expectancies on task performance; however, the role of fitness in relation to this aspect of cognitive performance has yet to be determined. This may be an area of cognition in which fitness plays a role due to the fact that it is an executive control task and fitness has been found to be beneficial to executive control. A consequential study by Gratton et al. (1992) demonstrated an interesting effect of expectancies on response time and accuracy on the flanker task. The specific variable they examined was noise level, or the degree to which flanking stimuli either activate the correct response by matching the target stimulus or activate the incorrect response because of their discrepancy from the target stimulus. The variable was termed *noise* because it essentially reflects the amount of distraction that flanking stimuli present through their agreement or disagreement with the target stimulus. For example, in conditions with a high presence of noise, calling incongruent trials, flanking stimuli differ from the target stimulus (<<><< or >><>>), while conditions without noise, or congruent trials, have flanking stimuli that match the target stimulus (<<<<< or >>>>>).

Gratton and colleagues (1992) found that participants responded faster and more accurately on incongruent trials when following previous incongruent trials than when following congruent trials, perhaps because their cognitive systems were prepared for a challenge after previously being challenged. Further analyses indicated that this effect resulted from the repeat of noise level and not the repeat of specific stimuli (Gratton et al., 1992). Other researchers have described this effect as a "selection-for-action," or a series of cognitive processes that lead to choosing the target stimulus and responding to it (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999, p. 179). According to these researchers, the Gratton effect is due to a greater selection-for-action triggered by incongruent trials, which reduces the effect of noise on the following incongruent trial (Botvinick et al., 1999). Participants expect a repeat in stimulus conditions such that an incongruent trial will follow an incongruent trial and a congruent trial will following a congruent trial, leading to better performance on incongruent trials following a previous incongruent trial (iI trials) compared to incongruent trials following a previous congruent trial (cI trials; Gratton et al., 1992).

In terms of reaction time, results of Gratton et al.'s (1992) study revealed a significant interaction between noise on the previous trial (or congruency between target and flanking stimuli) and the effect of noise on performance such that interference had a larger effect on performance following a congruent trial than an incongruent trial. In other words, a greater difference existed between reaction time (RT) on incongruent and congruent trials when following a congruent trial compared to when following an incongruent trial. Gratton et al. (1992) hypothesized that, following a congruent trial, participants devote more attention to an early phase of cognitive processing characterized by parallel processing, which is generally faster and more automatic, whereas after an incongruent trial participants rely more heavily on the later phase of cognitive processing, which uses a focused strategy that conjoins different aspects of stimulus information. Gratton and colleagues' (1992) study demonstrates that people can exert control over their information-processing system based on their expectancies.

The current study will investigate the role of cardiorespiratory fitness in the expectancy effect that Gratton et al. (1992) found, the so-called Gratton effect (Botvinick et al., 1999). This potential element of the overall effect of cardiorespiratory fitness on cognition has not yet been discussed in the literature, but filling this gap in the existing literature may provide additional clues to the specific role that fitness plays in affecting cognitive performance on executive control tasks.

Neuroelectric Indices of Cognition

In addition to behavioral measures, assessments of electric brain waves are also useful in studying cognitive functioning because electric brain waves reveal the underlying cortical activity during the performance of cognitive tasks. Electroencephalographic (EEG) activity in the form of stimulus-locked event-related potentials (ERPs) has frequently been utilized to measure continuous neuroelectic behavior in response to a cognitive task. One specific component of a stimulus-locked ERP that has repeatedly been measured in cognitive studies is the P3, a positive endogenous waveform that usually peaks between 300 and 800 milliseconds (ms) after the onset of a stimulus and is characterized by maximal distribution over the scalp (Gehring, Gratton, Coles, & Donchin, 1992). The P3 represents the allocation of attention to a cognitive task, which is supported by the finding that P3 amplitude increases with the amount of attention devoted to a task (Hillman et al., 2005). Figure 1 presents an example of the P3 component.

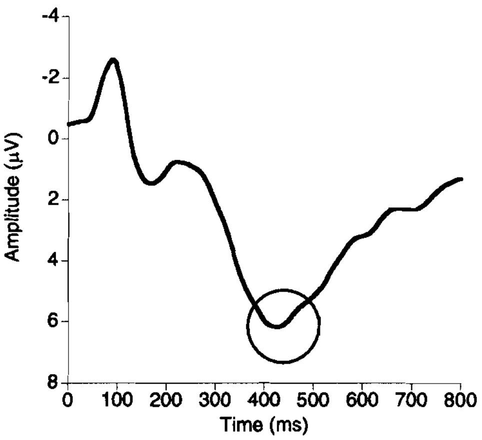


Figure 1. Grand average stimulus-locked ERP from the present study highlighting the P3 waveform.

Two components of the P3 that are commonly analyzed are the amplitude, measured in microvolts (μV), and the latency, measured as time (ms) from the onset of the stimulus. P3 amplitude is believed to be indicative of the intensity of mental processing (Kok, 2001). Hillman and colleagues (2005) suggested that greater P3 amplitude may represent increased synchrony of neuron firing during a cognitive task. P3 amplitude has furthermore been explained as the capacity of attention that can be utilized in categorizing information pertaining to the target stimulus (Kok, 2001) and the frequency of working memory updating during a task (Hillman et al., 2005). Finally, Gehring and colleagues (1992) suggested that changes in P3 amplitude indicate changes in the degree of neural activation. In the current study, P3 amplitude was measured to assess task-relevant allocation of attention.

The second aspect of the P3 waveform, latency, is thought to reflect the timing of cognitive processes during the completion of a task (Kok, 2001) and the speed of neurocognitive processing (Hillman et al., 2005). Gehring et al. (1992) attribute changes in P3 latency to variations in the duration of mental processes occurring prior to the P3. In the current study, participants' P3 amplitude and latency were measured during a cognitive task to determine whether or not these measures were correlated with increased cardiorespiratory fitness.

Fitness Effects on Neuroelectric Activity

Researchers have discovered significant effects of physical fitness on neuroelectric behavior that provide additional information about the mental processes underlying the benefits of fitness on cognitive performance. When comparing group of high- and low-fit adults and children, Hillman et al. (2005) found that high-fit participants revealed greater P3 amplitude and faster P3 latency than low-fit participants, suggesting that aerobic fitness may predict increased neuroelectric activation responsible for cognitive functioning or may increase synchrony in neuron firing, which would therefore show different patterns in P3 amplitude and latency. Similarly, Hillman et al. (2003) found greater updating of working memory processes, as signified by heightened P3 amplitudes, in people following acute bouts of cardiovascular activity, suggesting that cardiovascular activity is beneficial to executive control function.

Hillman et al. (2006a) found that more physically active individuals exhibited increased P3 amplitudes at central and parietal scalp sites. This group of researchers also discovered that a greater difference existed between the P3 amplitudes of active and sedentary individuals while completing more difficult tasks (utilizing executive control processes) than on easier tasks (Hillman et al., 2006a). The benefits of exercise on P3 latency were also greater for more difficult tasks. These data suggest that, while fitness has general effects on cognition, it has the greatest effect on executive control processes (Hillman et al., 2006a). A study by Hillman and colleagues (2003) resulted in similar conclusions. These researchers found shorter P3 latencies after bouts of aerobic exercise only during more difficult trials of a task, suggesting that exercise has a greater effect on effortful executive control tasks than tasks that require minimal cognitive effort (Hillman et al., 2003).

In summary, studies of the effects of fitness on neuroelectric behavior indicate a correlation between increased fitness or activity level and greater attention allocated to a cognitive task as well as faster processing speed, as evidenced by the amplitude and latency of the P3 component of the ERP. Multiple studies have also supported the idea that fitness has the most pronounced effects for neuroelectric behavior on cognitive tasks requiring executive control.

Current Study: Rationale and Hypotheses

A number of studies have examined the effects of cardiorespiratory fitness on accuracy and reaction time in cognitive tasks or on amplitude and latency of the P3, but few studies (Hillman et al., 2005; Themanson & Hillman, 2006) have integrated fitness with both behavioral and neuroelectric indices of cognition into one study. Some studies that have combined all of these factors have estimated cardiorespiratory fitness using a self-report measure (Hillman et al., 2005) instead of the GXT for measuring maximal oxygen uptake (VO_{2max}), which is accepted as the “gold standard” measure of aerobic fitness (American College of Sports Medicine, 2000). Furthermore, previous studies have frequently involved the creation of arbitrary groups based on fitness level (Colcombe & Kramer, 2003; Hillman et al., 2005; Themanson & Hillman, 2006), which may exclude important information because fitness naturally exists on a continuum and may be better understood when examined as a continuous variable. Finally, previous studies on fitness and cognition did not arrive at a consensus in regard to varying effects on different age groups. Many studies target specific populations such as elderly adults (Hillman et al., 2004) or young children (Hillman et al., 2005), but a gap exists in solid conclusions of the effects of fitness on the cognition of young adults.

Moreover, no researchers to date have examined the effects of fitness on the interaction between expectancies and task difficulty that Gratton et al. (1992) discussed. Researchers in the field have yet to discover if increased fitness enhances the effect of expectancies (resulting from noise on the previous trial) on responses to congruent or incongruent trials of the flanker task. This process of being better prepared for a difficult task following a prior difficult task may exist in numerous real-world situations. Expectancies may help students perform better on difficult exam questions following previous difficult questions or may allow people of all ages to devote more attention to challenging situations after previously being presented with equally challenging problems. It is possible that being more physically fit as a result of long-term commitment to aerobic exercise allows people to more effectively use task expectancies to modify their cognitive processing strategies. Discovering the answer to this question may have important implications for determining the mechanisms by which fitness impacts cognition and greater specificity in the role of fitness on cognitive behavior.

In the current study, physical fitness was approached as a continuous variable and measured using a GXT to obtain values of maximal oxygen uptake (VO_{2max}) for all participants. The variables that were expected to vary with physical fitness were performance on a cognitive task, measured by reaction time and accuracy on trials of the flanker task, and neuroelectric behavior, measured using ERP technique. The current study attempted to extend the breadth of knowledge in the field by examining the effects of cardiovascular fitness on task performance and attentional allocation in young adults, as well as the interplay between physical fitness and expectancies on task performance. Based on previous findings that fitness has a significant effect on tasks involving high-order executive control processes (Colcombe & Kramer, 2003; Hillman et al., 2006b), I predicted a specific effect of fitness on behavior such that increased fitness would correlate with higher accuracy and shorter reaction time on more difficult (incongruent) trials of the flanker task. I hypothesized a second specific effect of fitness on behavior that would demonstrate an association between increased fitness and a greater improvement on incongruent trials following incongruent trials. In other words, I predicted that increased fitness would correlate with a greater increase in accuracy and greater decrease in reaction time, specifically on difficult (incongruent) trials following previous difficult (incongruent) trials.

Furthermore, in agreement with previous conclusions (Hillman et al., 2003; Hillman et al., 2005), I expected to find a specific effect of fitness on neuroelectric behavior, with increased fitness corresponding to larger P3 amplitude and decreased P3 latency on difficult (incongruent) trials, corresponding to increased attention allocated to the task and shorter processing time. Finally, the second specific effect of fitness on neuroelectric behavior that I hypothesized was that increased fitness would predict a greater increase in P3 amplitude and a greater decrease in P3 latency on incongruent trials following incongruent trials.

Method

Participants

The current study involved a new analysis of previously collected data. Specifically, 72 young adults (ages 18-25) were recruited from undergraduate kinesiology courses at the University of Illinois at Urbana-Champaign to participate in the study. Each undergraduate student in these courses was given a confidential sign-up sheet for the study that included basic questions about the student's physical activity. The purpose of this brief questionnaire was to verify that participants in the study would represent a wide range of cardiorespiratory fitness levels. Students who agreed to participate in the study were given extra credit in their kinesiology course. Participants completed an informed consent form and received a brief description of the testing procedures before testing began.

Four participants who performed below 50% accuracy were excluded because performing below chance levels suggests that they may not have had an understanding of the task. Two participants who exhibited a body mass index (BMI) more than three standard deviations from the sample mean were also excluded because these participants were extreme outliers in the group and were considered unhealthy and at high risk of disease (ACSM, 2000.) Remaining participants were between 18 and 30 years of age and had an intelligence quotient (IQ) within the normal range according to the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990). Twenty-six participants were males and 40 participants were females. All participants demonstrated a corrected visual acuity of 20/40 or better. None of the participants exhibited any physical disability prohibiting physical activity.

A power analysis was conducted prior to data collection using nQuery Advisor 6.0 (Elashoff, 2005) to estimate the sample size necessary for finding a significant effect. Potential confounding variables, participant attrition, and potential problems with ERP data collection were considered in the analysis. Results indicated that a sample size above 54 would yield adequate power (B = 0.80).

Setting and Apparatus

Fitness Testing. Cardiorespiratory fitness was assessed using a maximal graded exercise test (GXT) that measures maximum oxygen consumption ($V0_{2max}$) during a bout of physical activity. The test took place in the Physical Fitness Research Laboratory in the Department of Kinesiology and Community Health at the University of Illinois at Urbana-Champaign. A motor-driven treadmill was utilized according to a modified Balke protocol (ACSM, 2000). Participants walked/ran on a motor-driven treadmill at a constant speed, which was established for each individual based on their three-minute warm-up pace. The grade was increased by 2% increments every two minutes. Participants were instructed to keep going until volitional exhaustion, at which point the test was completed.

Oxygen uptake was measured continuously using open-circuit spirometry (ParvoMedics True Max 2400, Sandy, UT). Through this technique, participants breathed through a tube connected to a computer that measured air composition. Participants' noses were plugged to ensure that all air being inhaled and exhaled would be through the mouth and therefore detected by the computer. Maximal oxygen uptake ($V0_{2max}$) was measured from expired air samples taken at 30-second intervals during the test. $V0_{2max}$, in the units of milliliters (mL) per kilogram (kg) per minute (min), is typically defined as the greatest oxygen uptake corresponding to at least two of the following criteria: a) a plateau in oxygen consumption ($V0_2$) with increasing work load; b) maximal heart rate with 10 beats per minute (bpm) of the age-predicted maximum (calculated as 220 bpm minus age in years); and c) a respiratory exchange ratio (RER) greater than 1.10, indicating that the body is working at a loss by expelling more carbon dioxide ($C0_2$) in relation to the oxygen (0_2) being taken in. Heart rate was measured using a wireless Polar heart rate monitoring system. Two exercise test technologists who were certified in First Aid and cardiopulmonary resuscitation (CPR) monitored and supervised the test.

Cognitive Task. Participants completed the cognitive task in a classroom containing a chair and a computer. The lights were dimmed in the room to limit ambient electrical voltage that would be picked up by the EEG. Participants sat in the chair with both feet on the ground with a distance of exactly one meter from their eyes to the computer screen. In each hand they held a controller connected to the computer that would allow them to respond to stimuli on the computer screen by pressing down on the button in the controller. The only person present in the room was the participant.

Participants completed a modification of the Eriksen flanker task (Eriksen & Eriksen, 1974), which included congruent and incongruent conditions presented in randomized order. Each trial of the task consisted of an array of five arrows presented on the screen. Participants were instructed to focus on the center arrow and press the button corresponding to the direction of the center arrow. In the congruent condition, all arrows pointed in the same direction (">>>>>" or "<<<<<"). In the incongruent condition, flanking stimuli differed from the target stimuli (">><>>" or "<<><<"). Trials were grouped into two blocks of 300 trials each with a brief rest period in between each block. Within each block, there were exactly 75 congruent trials with arrows pointing left ("<<<<<"), 75 congruent trials with arrows pointing right (">>>>>"), 75 incongruent trials with the target stimulus pointing left (">><>>"), and 75 incongruent trials with the target stimulus pointing right ("<<><<"), presented in a randomized order. In one block, participants were instructed to respond as accurately as possible; in the other block, participants were instructed to respond as quickly as possible. The order of the blocks was counterbalanced across participants, with half of the participants being instructed to focus on accuracy first, and the other half of participants being instructed to first focus on speed.

Neuroelectric Assessment. Cortical electrical activity was measured during the cognitive task. Participants were prepared for neuroelectric assessment in accordance with the guidelines of the Society for Psychophysiological Research (Picton et al., 2000). A lycra electrode cap (Neuro, Inc., El Paso, TX) was fitted onto the participant's head, and 64 sintered Ag-AgCl electrodes (10 mm) were arranged in an extended 10-20 system montage. Electrodes were prepared using Quik gel (Neuro, Inc., El Paso, TX). The sites were referenced online to a midline electrode placed at the midpoint between Cz and CPz. AFz was used as the ground electrode. Ag-AgCl electrodes above and below the right orbit as well as at the outer canthus of each eye were used to record vertical and horizontal bipolar electrooculographic activity (EOG) in order to monitor eye movements. Eye movements and blinks create disturbances in the EEG data and were filtered out at a later point to create an accurate recording of cortical electrical activity.

Electrodes were referenced offline to the average mastoids to attain a measure of electrical activity specific to cortical activity. Impedances were kept below 10 kΩ for all electrodes. A Neuroscan Synamps2 bioamplifier (Neuro, Inc., El Paso, TX) with a 24 bit A/D converter and +/- 200 millivolt (mV) input range was used to continuously digitize (500 Hz sampling rate; Mathalon, Whitfield, & Ford, 2003), amplify (gain of 10), and filter (70 Hz low-pass filter, including a 60 Hz notch filter) the raw EEG signal in DC mode (763 μV/bit resolution). EEG activity was recorded using Neuroscan Scan software (v 4.3.1). Stimulus presentation, timing, and measurement of behavioral response time and accuracy were controlled by Neuroscan Stim (v 2.0) software.

Predictor Variables

Cardiorespiratory Fitness. Fitness was defined as maximum oxygen uptake (VO_{2max}) and was measured by the GXT test described above, providing a measure of maximal aerobic capacity. The experimenter read a consistent script of instructions to each participant. Fitness was treated as a continuous variable.

Participant Characteristics. Before fitness and cognitive testing, participants completed a series of questionnaires to ensure that other variables did not interfere with fitness effects. Participants were pre-screened for potential risk factors that may make physical exercise hazardous. The measure that was used was the Physical Activity Readiness Questionnaire (PAR-Q), which has been established as the standard screening protocol in the University of Illinois at Urbana-Champaign's Department of Kinesiology for exercise testing in young, apparently healthy adults and is based on ACSM (2000) guidelines. Participants completed a handedness inventory, the K-BIT (Kaufman & Kaufman, 1990) to estimate their IQ, and a health history and demographics questionnaire. They also had their height and weight measured to calculate their BMI.

Dependent Measures

Response Time and Accuracy. Behavioral indices of cognition were assessed using response time and accuracy on the flanker task. Response time was defined as the time (ms) from the presentation of the stimulus until the participant's response, and accuracy was the percentage of correct responses. Average response latencies and accuracy rates for each participant were calculated for all trials, all congruent trials, all incongruent trials, as well as each of the following combinations of trials: 1) congruent trials following congruent trials (cC), 2) congruent trials following incongruent trials (iC), 3) incongruent trials following congruent trials (cI), and 4) incongruent trials following incongruent trials (iI). Out of these variables, average response time and accuracy for congruent, incongruent, cI, and iI trials were the main dependent measures for the present study, and analyses were also conducted on response time for cC and iC trials in each condition to determine whether or not the interaction effect that Gratton et al. (1992) detected was replicated. Global average latencies were also calculated for each participant. Each participant's average reaction time on cI trials was compared to his or her reaction time on iI trials in accordance with the Gratton effect. Similarly, participants' mean accuracy on cI trials was compared to their accuracy on iI trials.

Neuroelectric Activity. Cortical electrical activity was measured using the electrode cap (Neuro, Inc., El Paso, TX), Neuroscan Synamps2 bioamplifier (Neuro, Inc., El Paso, TX), and Neuroscan Scan software (v 4.3.1), as described above. Continuous EEG recordings were made for each participant at each electrode site, then divided into time-locked epochs, averaged to create stimulus-locked ERPs, and analyzed in relation to responses to stimuli in the cognitive task. Amplitude was measured as a change from the pre-stimulus baseline. The P3 was quantified as a positive deflection of ERP voltage peaking between 300 and 800 ms after the onset of a stimulus. Latency was measured as the time (ms) from the onset of a stimulus to the peak of the P3 waveform.

ERP Reduction

Following participants' completion of the cognitive task, data files of neuroelectric recordings and behavioral responses were aligned according to their temporal relationship and merged into one data file per participant. Following the creation of a single data file for each participant, eye blink artifacts were removed from the neuroelectic data using a spatial filter method (Compumedics Neuroscan, 2003). To do this, neuroelectric activity that occurred during eye blinks was first identified through temporal correspondence with the EOG data. Next, an average waveform associated with eye blinks was calculated, and this activity was removed from the data file for each eye blink using two consecutive spatial singular value decomposition (SVD) analyses. This transformation removes unwanted blink artifacts from the EEG recording, allowing true cortical activity to be analyzed more clearly.

Following the removal of blink artifacts from the data file, continuous EEG recordings were divided into stimulus-locked epochs reflecting the presentation of, and response to, a stimulus in each trial of the cognitive task. Epochs corresponding to incorrect responses were removed because amplitudes and latencies associated with incorrect responses do not reflect mental processes in the same way that amplitudes and latencies of waveforms associated with correct trials do. Also, stimulus-locked ERPs following error trials may contain waveforms associated with error-detection processes, which could contaminate the P3. The remaining epochs for each participant were then baseline-corrected so that all epochs began at the same starting amplitude (0.0 μV). This was done because the change in amplitude, not the absolute amplitude itself, is the focus of the current study and is independent of baseline amplitude. Epochs containing ambient noise, identified as waveforms greater/less than +/- 75 μV, which did not reflect true cortical activity, were also removed. Finally, all epochs at each channel for each participant were averaged together to create a single average ERP for each participant at each site that reflects cortical activity related to the stimulus. Analyses were conducted on P3 data at three specific sites (Fz, Cz, and Pz) at which P3 amplitude was maximal, resulting in a total of 42 variables for P3 amplitude and the same number for P3 latency.

Procedure

Data were collected on two separate days for each participant. On the first day, participants signed the informed consent, received a brief description of the testing procedures, completed paperwork and questionnaires, and performed the GXT to measure VO_{2max}. The session lasted approximately 90 minutes.

During the second session, participants were prepared for neuroelectic assessment and given the instructions of the cognitive task. Before each task block, participants completed practice trials and were given the opportunity to ask questions. Participants completed the flanker task while neuroelectric and behavioral responses were measured. Following the completion of the task, the electrode cap was removed and participants were debriefed on the purpose of the study. This session lasted approximately 120 minutes.

Statistical Analyses

Preliminary analyses involved bivariate correlations to detect any relationships between predictor and criterion variables and handedness, IQ, sex, BMI, or other demographics. In addition to VO_{2max} scores and demographic factors, a total of 28 behavioral variables were entered into the correlation matrix, as well as 84 neuroelectric variables. The 28 behavioral variables included accuracy and reaction time for seven trial types (congruent, incongruent, cC, iC, cI, iI, and a difference score between cI and iI) for both instruction conditions (speed and accuracy). The 84 neuroelectric variables included P3 amplitude and latency at three electrode sites (Fz, Cz, and Pz) for the same seven trial types in both instruction conditions. Separate paired samples *t*-tests were conducted to verify the manipulation of instruction condition and trial type such that accuracy was greater in the accuracy condition and reaction time was faster in the speed condition for all participants and that task performance on congruent trials was more accurate and faster than performance on incongruent trials. Two repeated measures ANOVAs were conducted to verify that P3 measurements were consistent with previous studies.

To test the hypotheses, multiple hierarchical regressions were performed on the 15 variables found to be significantly correlated with fitness in the bivariate correlations. This type of analysis calculated the overall association between the predictor variables (fitness and demographics) and the criterion (neuroelectric activity or task performance).

Any demographic variables that were determined to have a significant correlation with the criterion were entered in Step 1. This gave a complete explanation of the amount of variance in the criterion accounted for by all predictor variables. Then, in Step 2, VO_{2max} scores were entered in order to determine the unique influence of fitness on the criterion variable (accuracy, reaction time, P3 amplitude, or P3 latency) above and beyond all other associations.

Results

Participant Characteristics

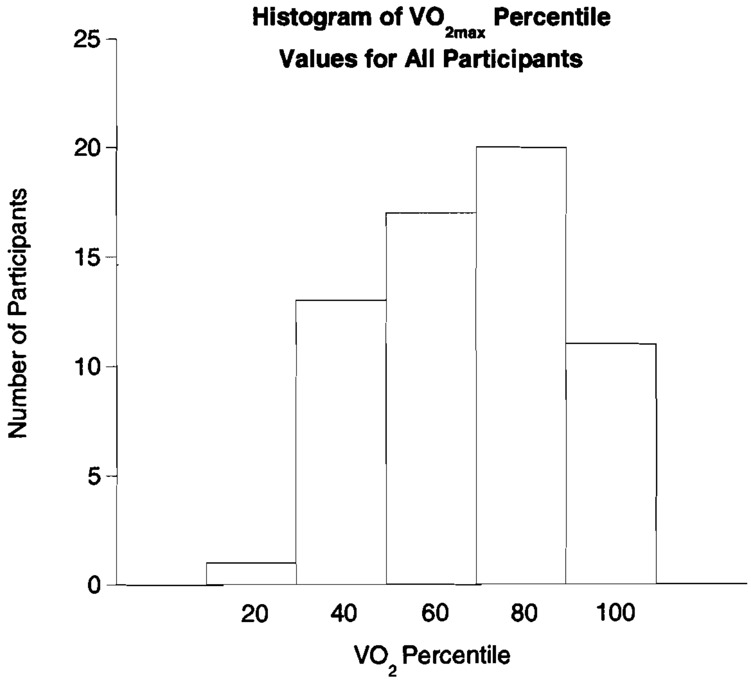
Participants were 66 undergraduate students (40 female) between the ages of 18 and 30 years. All participants demonstrated a normal level of intelligence (K-BIT composite > 94) and a healthy BMI (< 30 kg/m^2; ACSM, 2000). Table 1 describes demographic characteristics. In relation to fitness testing, all participants achieved an RER > 1.1 and a maximum HR > 90% of the age-predicted maximum, suggesting maximal effort during testing. As expected, VO_{2max} scores obtained during the graded maximal exercise test were significantly correlated with sex ($r = -0.77, p < .05$), with males having significantly higher VO_{2max} scores ($M = 51.20$, $SD = 6.99$) than females ($M = 38.18$, $SD = 4.01$), $t(64) = 9.63, p < .001$. Figure 2 displays participants' maximal oxygen consumption (VO_{2max}) as a function of age- and sex-referenced percentile values (ACSM, 2000).

Table 1

Demographic Characteristics for Participants

Variable	All Participants *M (SD)*	Males *M (SD)*	Females *M (SD)*
Sample size (n)	66	26	40
Age (years)	19.95 (2.11)	20.54 (2.85)	19.58 (1.36)
BMI	22.42 (2.71)	22.74 (2.66)	22.21 (2.75)
IQ (K-BIT composite)	108.11 (6.54)	108.81 (6.43)	107.65 (6.66)
VO_{2max} (mL/kg/min)	43.30 (8.34)	51.20 (6.99)	38.17 (4.01)

Figure 2. Histogram of all participants' percentile values for maximal oxygen uptake (VO_{2max}) obtained from the treadmill maximal graded exercise test (GXT).



Preliminary Analyses

Table 2 presents behavioral data for all participants for each trial type. Paired samples *t*-tests were conducted to verify the effect of instruction condition on performance on the flanker task. Analyses confirmed that participants performed more accurately when instructed to focus on accuracy ($M = 86.79$, $SD = 8.60$) than when instructed to focus on speed ($M = 78.75$, $SD = 9.16$), $t(65) = 8.46$, $p < .001$. Further, participants had a faster reaction time (RT) when instructed to focus on speed ($M = 352.07$, $SD = 39.91$) than when instructed to focus on accuracy ($M = 394.50$, $SD = 48.37$), $t(65) = 10.65$, $p < .001$.

Table 2

Behavioral Data (Response Accuracy and Reaction Time) Organized by Trial Type, Collapsed Across Instruction Conditions

Behavioral Measure	All Trials	C*	I	cC	iC	cI	iI
Accuracy (percent correct) *M (SD)*	82.77 (8.00)	86.64 (7.14)	78.90 (9.35)	86.90 (6.95)	86.33 (7.57)	77.49 (9.90)	80.44 (9.07)
Reaction time (ms) *M (SD)*	373.28 (41.28)	356.03 (38.24)	391.83 (44.18)	349.09 (37.47)	361.04 (39.49)	391.78 (45.47)	392.50 (44.81)

**Key for trial types: C=congruent, I=incongruent, cC=congruent following congruent, iC=congruent following incongruent, cI=incongruent following congruent, iI=incongruent following incongruent.*

Analyses were also conducted to verify the effect of trial type on flanker task performance. As expected, these analyses confirmed that participants performed faster during congruent trials ($M = 356.03$, $SD = 38.24$) compared to incongruent trials ($M =$

391.83, *SD* = 44.18), $t(65) = 27.78, p < .001$. They also performed more accurately on congruent trials ($M = 86.64$, $SD = 7.14$) compared to incongruent trials ($M = 78.90$, $SD = 9.35$), $t(65) = 13.97, p < .001$. These results reflected the fact that interference in the incongruent trials made these trials more difficult to perform than congruent trials, in which flanking stimuli matched the target stimulus.

Gratton Effect

Behavioral results reproduced the effect of expectancies on task performance described by Gratton et al. (1992), suggesting that participants are better prepared and perform faster or more accurately on tasks that match the previous task in degree of interference. The effects of expectancies on incongruent trials were analyzed using paired samples *t*-tests. When instructed to focus on accuracy, participants performed significantly more accurately on incongruent trials following a previous incongruent trial (iI) ($M = 84.68$, $SD = 10.03$) compared to incongruent trials following a congruent trial (cI) ($M = 82.41$, $SD = 11.08$), $t(65) = 4.16, p < .001$. A similar effect was seen when participants were instructed to focus on speed. In the speed condition, participants performed significantly more accurately on iI trials ($M = 76.21$, $SD = 10.10$) compared to cI trials ($M = 72.56$, $SD = 11.10$), $t(65) = 6.00, p < .001$. Figure 3 shows the replication of the Gratton effect for response accuracy when instructed to focus on accuracy.

The same effect of noise expectancies that was found for accuracy was detected for RT in the accuracy condition; however, the effect was not significant. Participants did not perform significantly faster on iI trials ($M = 413.49$, $SD = 51.59$) compared to cI trials ($M = 414.89$, $SD = 49.83$) in the accuracy condition, $t(65) = 0.83, p = .41$, but the results were in the expected direction. However, when instructed to focus on speed, there was a tendency for participants to perform faster on cI trials (*M* = 368.67, *SD* = 46.94) compared to iI trials (*M* = 371.52, *SD* = 44.49), *t*(65) = 5.78, *p* = .06.

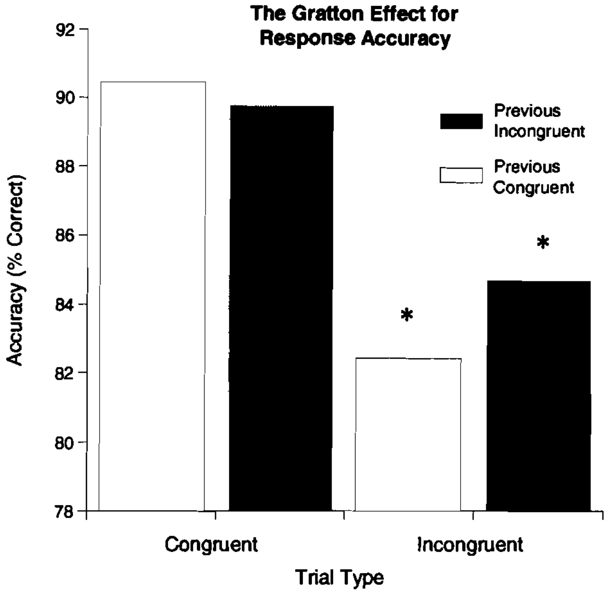


Figure 3. Mean accuracy for congruent and incongruent trials in the accuracy condition based on previous trial type. Accuracy on incongruent trials following an incongruent trial is significantly greater than accuracy on incongruent trials following a congruent trial, showing the replication of the Gratton effect for accuracy.

Despite these nonsignificant findings, the interaction between noise on the previous trial and the effect of noise on the current trial that Gratton et al. (1992) found was replicated and statistically significant for RT in the present study. A repeated measures ANOVA indicated that when instructed to focus on accuracy, noise had a stronger effect on RT when the previous trial was congruent. The difference between RT on cI (*M* = 414.89, *SD* = 49.83) and cC (*M* = 368.62, *SD* = 47.01) trials was greater than the difference between iI (*M* = 413.49, *SD* = 51.59) and iC (*M* = 382.25, *SD* = 48.54) trials, *F*(1,65) = 52.67, *p* < .001. Similarly, a second repeated measures ANOVA indicated that when instructed to focus on speed, a greater difference was seen between RT on cI (M = 368.67, SD = 46.94) and cC (M = 329.55, SD = 35.09) compared to iI (M = 371.52, SD = 44.49) and iC (M = 339.84, SD = 37.25), $F(1,65) = 17.58, p < .001$. These results demonstrate that noise had a greater effect on performance following an easy (congruent) trial compared to following a difficult (incongruent) trial. Thus, although a significant main effect for expectancies following an incongruent trial was not detected for RT, a significant interaction effect demonstrated the replication of the Gratton effect. Figure 4 presents this interaction effect for RT in the speed condition.

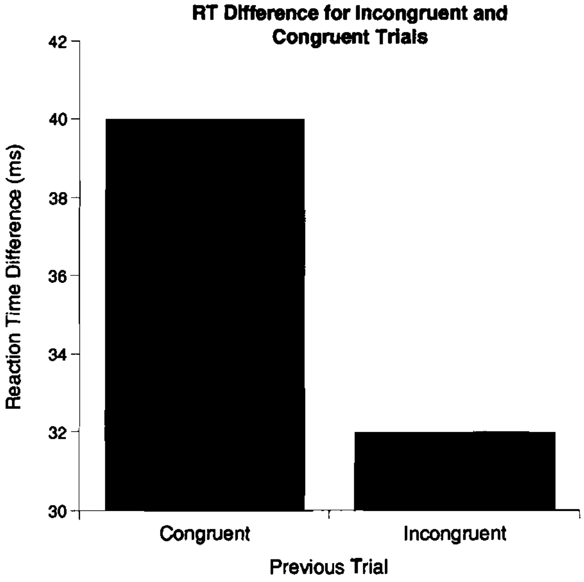


Figure 4. Mean reaction time (RT) for congruent and incongruent trials in the speed condition based on previous trial type. The difference in RT between trials following a congruent trial is significantly greater than the difference in RT between trials following an incongruent trial, showing the replication of the Gratton effect for RT.

Fitness and Behavioral Measures

Twelve multiple hierarchical regressions were performed for behavioral variables to determine the unique influence of fitness above and beyond the effects of other variables on accuracy and reaction time for congruent, incongruent, cC, iC, cI, and iI trials in each instruction condition. The only variable that appeared to be significantly correlated with any dependent measure was age. Sex was also included in the regression because fitness level is related to sex, as equations for calculating VO_{2max} vary for males and females, and the same VO_{2max} is associated with different levels of fitness for males and females (ACSM, 2000). Results verified that fitness had a strong correlation with sex such that males had higher VO_{2max} scores than females ($r = -0.77, p < .001$). In the hierarchical regressions, sex was entered in Step 1, along with age for those variables with which age was significantly correlated, and fitness was entered in Step 2.

Fitness was not significantly correlated with response accuracy in any instruction condition or trial type on the flanker task. In the accuracy condition, fitness was not correlated with percent correct on congruent ($p = .25$) or incongruent trials ($p = .71$). Similarly, in the speed condition, fitness was not correlated with percent correct on congruent ($p = .51$) or incongruent trials ($p = .29$). Therefore, no hierarchical regressions were computed for response accuracy.

Although bivariate correlations showed that fitness was correlated with RT, results of multiple hierarchical regressions demonstrated that fitness had no significant influence on RT above and beyond the effects of age or sex on performance of any trial type on the flanker task. In the accuracy condition, sex had a significant effect on RT for congruent trials, $t(63) = 3.91, p < .001$, as did age, $t(63) = 3.81, p < .001$, but the influence of fitness above and beyond the effects of these variables was not significant, $\Delta R^2 = 0.00$, $F(1, 62) = 0.00$, $p = .96$. Sex had a significant effect on RT for incongruent trials, adjusted $R^2 = 0.10$, $F(1, 64) = 8.21$, $p < .01$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00$, $F(1, 63) = 0.03$, $p = .86$.

Further, for cC trials, sex had a significant effect on RT, $t(63) = 4.04$, $p < .001$, as did age, $t(63) = 4.01$, $p < .001$, but the influence of fitness above and beyond the effects of these variables was not significant, $\Delta R^2 = 0.00$, $F(1, 62) = 0.01$, $p = .94$. For iC trials, sex had a significant effect on RT, $t(63) = 3.70$, $p < 0.001$, as did age, $t(63) = 3.58$, $p < .01$, but the influence of fitness above and beyond the effects of these variables was not significant, $\Delta R^2 = 0.00$, $F(1, 62) = 0.02$, $p = .88$. For cI trials, sex had a significant effect on RT, adjusted $R^2 = 0.10$, $F(1, 64) = 8.27$, $p < .01$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00$, $F(1, 63) = 0.07$, $p = .79$. Finally, for iI trials, sex had a significant effect on RT, adjusted $R^2 = 0.11$, $F(1, 64) = 8.62$, $p < .01$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00$, $F(1, 63) = 0.21$, $p = .65$.

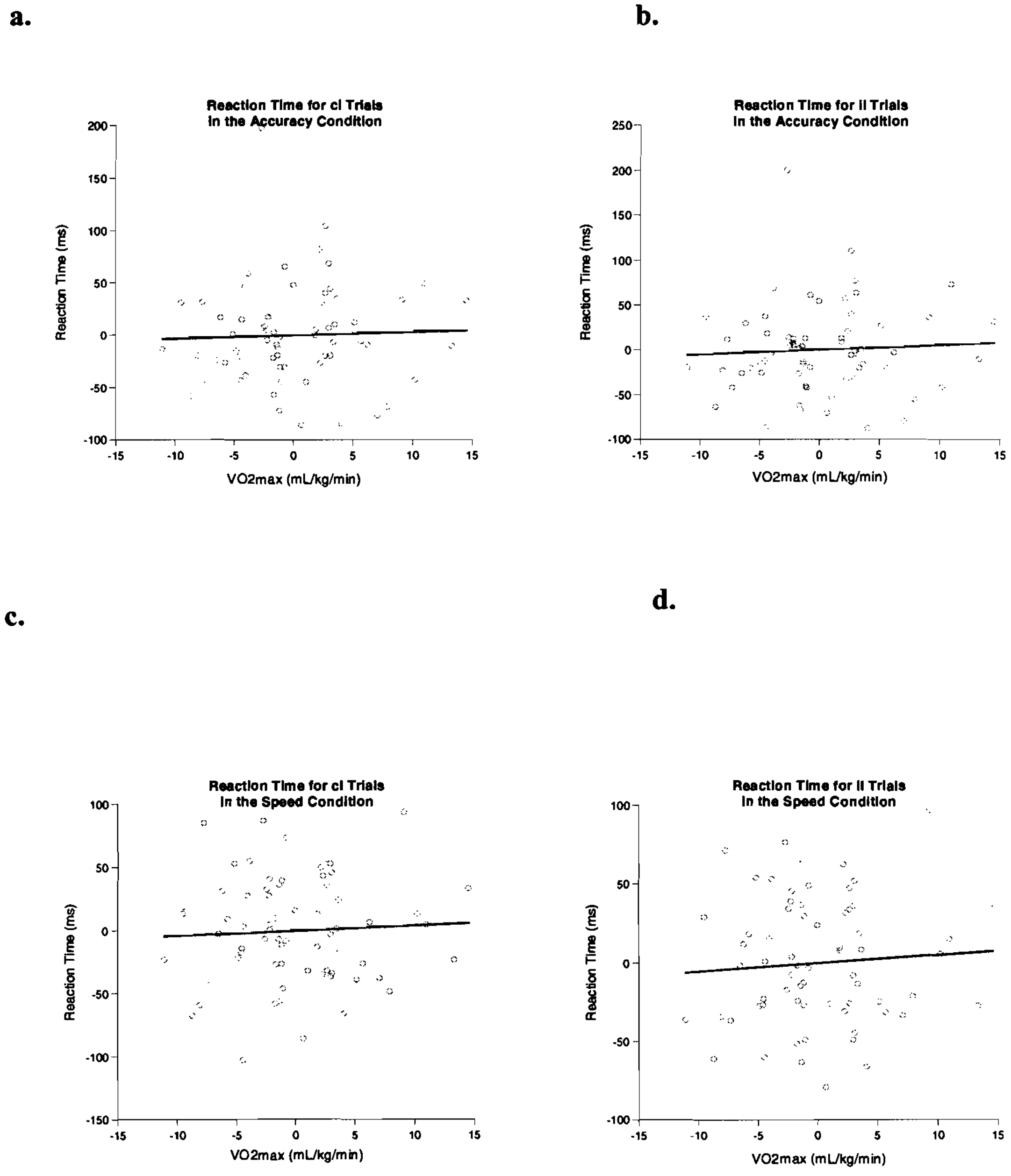
Similar results were seen when participants were instructed to focus on speed. For congruent trials, sex had a significant effect on RT, adjusted $R^2 = 0.18$, $F(1, 64) = 15.32$, $p < .001$, but the influence of fitness was not significant, $\Delta R^2 = 0.00$, $F(1, 63) = 0.02$, $p = .90$. For incongruent, sex had a significant effect on RT, adjusted $R^2 = 0.20$,

$F(1, 64) = 17.56, p < 0.001$, but the effect of fitness was not significant, $\Delta R^2 = 0.00, F(1, 63) = 0.20, p = .65$.

For cC trials, sex had a significant effect on RT, adjusted $R^2 = 0.17, F(1, 64) = 12.84, p < .01$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00, F(1, 63) = 0.01, p = .94$. For iC trials, sex had a significant effect on RT, adjusted $R^2 = 0.20$, $F(1, 64) = 16.76, p < .001$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00, F(1, 63) = 0.02, p = .88$. For cI trials, sex had a significant effect on RT, adjusted $R^2 = 0.18, F(1, 64) = 14.86, p < .001$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00, F(1, 63) = 0.16, p = .69$. Finally, for iI trials, sex had a significant effect on RT, adjusted $R^2 = 0.23, F(1, 64) = 20.45, p < .001$, but the unique influence of fitness was not significant, $\Delta R^2 = 0.00, F(1, 63) = 0.34, p = .56$.

Fitness did not exhibit a significant relationship with the behavioral indices of the Gratton effect. Specifically, fitness was not significantly correlated with a difference between accuracy on cI trials and iI trials in the accuracy condition ($p = .24$) or the speed condition ($p = .52$). Fitness was also not significantly correlated with a difference between RT on cI and iI trials in the accuracy condition ($p = .97$) or the speed condition ($p = .65$). Figure 5 shows the relationship between residuals for fitness and RT after controlling for the influence of sex.

Figure 5. Fitness and RT results. (a) Scatter plot for the relationship between residuals for fitness and RT for incongruent trials following congruent trials (cI) in the accuracy condition after controlling for the influence of sex. (b) Scatter plot for the relationship between residuals for fitness and RT for incongruent trials following incongruent trials (iI) in the accuracy condition after controlling for the influence of sex. (c) Scatter plot for the relationship between residuals for fitness and RT for incongruent trials following congruent trials (cI) in the speed condition after controlling for the influence of sex. (d) Scatter plot for the relationship between residuals for fitness and RT for incongruent trials following incongruent trials (iI) in the speed condition after controlling for the influence of sex.



Neuroelectric Analyses

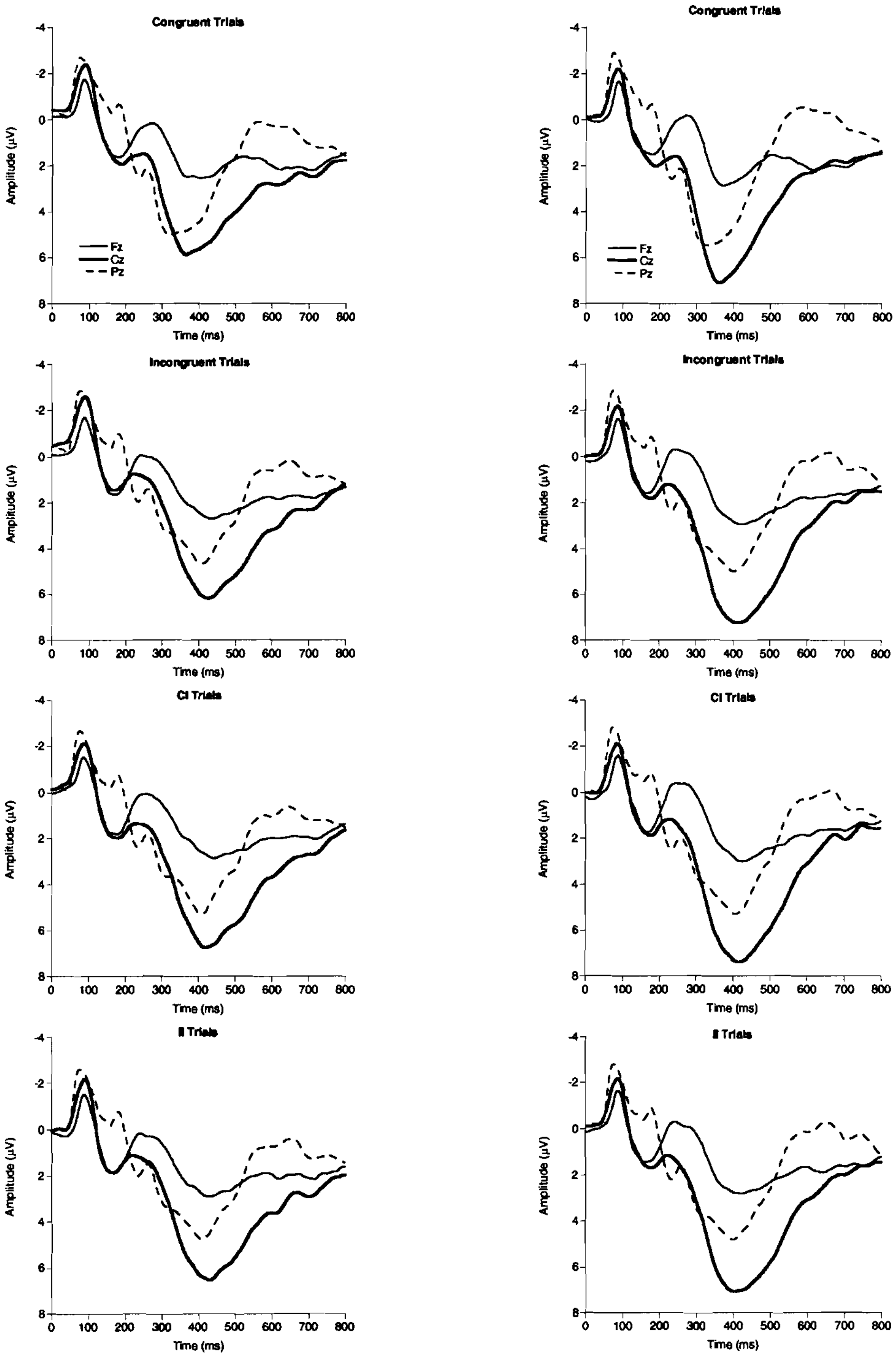
The P3 component was defined as the largest positive going waveform detected between 250 and 650 ms after the presentation of the stimulus. P3 amplitude was measured relative to the pre-stimulus baseline, and latency was defined as the temporal point at which P3 amplitude was maximal. Neuroelectric analyses were based on the Fz, Cz, and Pz electrode sites, which are the sites that previous researchers have used in their analyses (Conroy & Polich, 2007; Katayama & Polich, 1999; Lardon & Polich, 1996; Polich & Lardon, 1997). Figure 6 presents grand average ERPs at these sites based on trial type.

Two repeated measures ANOVAs were performed to determine whether or not the P3 component exhibited the expected topography. P3 amplitude was greatest at Cz, $F(2, 64) = 48.29, p < .001$. This is in line with conventional findings (Kok, 2001). P3 amplitude at Cz ($M = 7.84, SD = 3.94$) was significantly larger than at Pz ($M = 6.65, SD = 4.61$), $p < .01$. Furthermore, P3 amplitude at Pz was significantly larger than at Fz ($M = 4.26, SD = 2.86$), $p < .001$.

P3 latency decreased from frontal to parietal sites, $F(2, 64) = 24.59, p < .001$, which is also consistent with previous findings (e.g., Hillman et al., 2005). Latency at Pz ($M = 361.58, SD = 63.80$) was significantly faster than at Cz ($M = 414.27, SD = 70.19$), $p < .001$. Furthermore, P3 latency at Cz was significantly faster than at Fz ($M = 467.80$, $SD = 95.78$), $p < .001$.

Figure 6. Grand average stimulus-locked ERPs for congruent, incongruent, incongruent following congruent (CI), and incongruent following incongruent (II) trials of the flanker task.

Accuracy Condition *Speed Condition*



Effects of Fitness on Neuroelectric Measures

Bivariate correlations were conducted to determine relationship between fitness and P3 amplitude and latency at Fz, Cz, and Pz for all trial types (congruent, incongruent, cC, iC, cI, and iI) in both instruction conditions. A total of 84 dependent measures were included in the correlation, but only three measures were found to correlate significantly with fitness, and therefore only three multiple hierarchical regressions were conducted for neuroelectric variables. In the accuracy condition, fitness was significantly and positively correlated with P3 latency at the Cz site for incongruent trials ($r = 0.29, p < .05$). Hierarchical regressions confirmed that sex did not have a significant on P3 latency at the Cz site for these types of trials, adjusted $R^2 = 0.01$, $F(1, 64) = 1.92, p = .17$, but the influence of fitness above and beyond the influence of other variables was significant, with fitness being related to greater latency of the P3, $\Delta R^2 = 0.03$, $F(1, 63) = 0.31, p < .05$. However, this relationship was found to have a small effect size (Cohen's $f^2 = 0.02$).

Fitness was not significantly correlated with P3 latency for incongruent trials at Fz ($p = .36$) or Pz ($p = .88$). Fitness was not significantly correlated with P3 amplitude for incongruent trials at any of the sites: Fz ($p = .73$), Cz ($p = .94$), Pz ($p = .95$). For congruent trials, fitness was not correlated with P3 latency at Fz ($p = .47$), Cz ($p = .26$), or Pz ($p = .83$), or with P3 amplitude at Fz ($p = .72$), Cz ($p = .91$), or Pz ($p = .57$).

In the speed condition, bivariate correlations showed a significant relationship between fitness and P3 amplitude for congruent trials at Fz, but hierarchical regressions demonstrated that neither sex, $t(63) = 1.29, p = .20$, age $t(63) = 1.85, p = .07$, or fitness, $\Delta R^2 = 0.03$, $F(1, 62) = 2.12, p = .15$, had a significant unique influence on this variable.

Fitness was not significantly correlated with P3 amplitude for congruent trials at Cz (p = .15) or Pz (p = 1.00), or for incongruent trials at Fz (p = .10), Cz (p = .33), or Pz p = .74). Further, fitness was not significantly correlated with P3 latency for congruent trials at Fz (p = .58), Cz (p = .95), or Pz (p = .73) or incongruent trials at Fz (p = .46), Cz (p = .71), or Pz (p = .53).

Fitness and the Gratton Effect on Neuroelectric Measures

In terms of the expectancy effects that Gratton et al. (1992) discussed, fitness was significantly and negatively correlated with a difference in P3 amplitude between iI trials and cI trials in the speed condition at the Cz electrode site (r = -0.24, $p < .05$), with increased fitness corresponding to a lesser difference between amplitude for these two trial types. Hierarchical regressions confirmed that the effect of sex on this difference score was not significant, adjusted R^2 = -0.01, $F(1, 64)$ = 0.33, p = .57, but the influence of fitness above and beyond the influence of other variables was significant, ΔR^2 = 0.09, $F(1, 63)$ = 3.18, $p < .05$. However, this relationship was found to have a small effect size (Cohen's f^2 = -0.04). No other effects were significant for the relationship between fitness and the Gratton effect in terms of neuroelectric measures in either instruction condition. Specifically, fitness did not have a significant effect on difference scores between P3 amplitude for iI and cI trials at Fz or Pz in the speed condition or Fz, Cz, or Pz in the accuracy condition. Moreover, fitness did not have a significant effect on the difference between P3 latency for iI and cI trials in any of these six conditions.

Discussion

The present study was conducted to extend the previously existing breadth of knowledge on the potential beneficial effects of fitness on cognition. Specifically, the present study examined the influence of fitness on the effect of noise expectancies on task performance (Gratton et al., 1992) in an attempt to further understand the specific situations in which fitness may relate to improved cognition. In sum, the current study replicated the effects of noise expectancies on task performance that Gratton et al. (1992) described. Results also demonstrated that greater fitness correlated with a lesser difference between P3 amplitude across expectancies and with a longer P3 latency for incongruent trials at one site in one instruction condition. However, no relationship was observed between cardiorespiratory fitness and behavioral indices of the Gratton effect.

Replication of the Gratton Effect

In the current study, the effects of noise expectancies on task performance that Gratton et al. (1992) described were replicated. I found that participants performed more accurately on difficult trials of the flanker task when following a previous difficult trial compared to when following a previous easy trial. In other words, the interference caused by incongruent flanking stimuli seemed to have less of an effect when the subjects expected that level of noise compared to when they were primed to expect a low degree of noise. This suggests that young adults are able to modify their cognitive problem-solving strategies based on cues from the task, specifically the cues provided by noise level on the previous trial.

Furthermore, the interaction effect between noise expectancies and the effects of noise on reaction time that Gratton et al. (1992) found were replicated. Specifically, interference had a greater effect on reaction time following a congruent trial compared to an incongruent trial. This suggests that young adults may devote more attention to the earlier, faster parallel processing stage of information processing when presented with an easier task, causing the difficulty of the following task to affect their performance to a greater degree. When given a difficult task, however, young adults may devote more attention to a later, focused strategy of cognitive processing, allowing them to better assess task interference and more effectively respond to it (Gratton et al., 1992). Botvinick et al. (1999) described this as a greater selection-for-action triggered by incongruent trials, allowing the effects of noise on task performance to be diminished on the following trial. Independent of physical fitness level, it can be concluded that healthy, young adults are, on average, able to effectively use information previously presented to them to solve the task at hand. This is an important higher-level problem-solving strategy that may be beneficial to driving a car, taking an exam, or other situations young adults encounter.

Fitness and Task Performance

The task that was employed to measure cognitive performance was the Eriksen flanker task, which measures interference control, requiring participants to ignore distracting flanker stimuli while focusing on, and responding to, the central target (Eriksen & Eriksen, 1974). In terms of behavioral performance, I hypothesized that greater cardiorespiratory fitness would correlate with increased accuracy and faster RT on difficult trials of the flanker task. Furthermore, I predicted that this effect would be amplified on iI compared to cI trials due to the Gratton effect. Previous research has found that people who participate in more frequent physical activity respond more quickly on the flanker task and, for older adults, more accurately as well (Hillman et al., 2006b). Other researchers have also found a correlation between greater fitness and better task performance (Themanson & Hillman, 2006), specifically on tasks that require executive control (Kramer et al., 1999). However, in the current study, no relationship was observed between cardiorespiratory fitness and behavioral measures.

One possible explanation for why no correlations were found between cardiorespiratory fitness and behavioral indices of cognition may be that participants were healthy, young adults who are in their peak years of cognitive performance (Salthouse & Davis, 2006). Therefore, there may not have been room for behavioral effects. This group of people may already be performing at maximum efficiency, causing any potential effects of fitness to be masked. Researchers have found that fitness is positively correlated with behavioral performance in older adults populations (Colcombe et al., 2004) and children (Hillman et al., 2005), but perhaps young, healthy adults already perform well enough on the flanker task that an improvement due to greater fitness would not be detectable.

Other studies have shown that more physically active young adults respond more quickly on the flanker task (Hillman et al., 2006b) and more quickly and accurately in a task-switching paradigm (Hillman et al., 2006a) compared to less active young adults, but physical activity does not necessarily equate with cardiorespiratory fitness, and many studies have not shown a relationship between increased cardiorespiratory fitness and improved behavioral performance on the flanker task in young adults. In one study in which cardiorespiratory fitness was assessed, Themanson and Hillman (2006) did not find a relationship between fitness and accuracy or RT on the flanker task, but they did find that higher-fit young adults showed better performance on other behavioral measures of the flanker task such as post-error response slowing. Researchers have often focused on older adult populations while using young adult cohorts as the control group (Hillman et al., 2004), but it is important to determine whether fitness can produce noticeable effects in young adults as well, and finding significant results in a population that is already performing with high efficiency and accuracy would be more meaningful than finding results in groups of people whose cognition is not already at peak levels.

Fitness and the P3

In terms of neuroelectric indices of cognition, I hypothesized that greater cardiorespiratory fitness would correlate with greater P3 amplitude and shorter P3 latency on difficult (incongruent) trials of the flanker task due to the fact that these types of trials require greater executive control in the form of interference control (Themanson & Hillman, 2006). Previous research has found that higher-fit people exhibit larger P3 amplitudes and shorter P3 latencies than low-fit people (Hillman et al., 2005), demonstrating greater allocation of attention to the task and faster cognitive processing (Kok, 2001). Furthermore, researchers have found that the benefits of physical activity on P3 amplitude and latency are more pronounced on difficult tasks (Hillman et al., 2006a). My hypotheses were not supported by the current data, however, because fitness was not related to greater P3 amplitude or shorter P3 latency, but was in fact related to longer P3 latency for incongruent trials at Cz when participants were instructed to focus on accuracy.

One explanation for the finding that greater fitness is correlated with longer P3 latency could be that participants with greater cardiorespiratory fitness were more likely to focus increased attention on the main objective of the task (which, in the accuracy condition, was to perform as accurately as possible) and devote less attention to secondary goals (i.e. speed of processing), suggesting a longer delay in RT, which was evident, though not statistically significant. Another possibility is that increased cardiorespiratory fitness is related to slower cognitive processing on difficult tasks and that the current results represent what is actually occurring in the cortex. However, this is unlikely due to the fact that fitness was not related to longer P3 latency for any other trial type at any site in either instruction condition. The small effect size of this finding suggests that many other variables in addition to fitness were involved in this latency difference and that the timing of the P3 component is dependent upon other factors that were not examined in the current study.

My second hypothesis for the effects of fitness on neuroelectric indices of cognition was that the predicted relationship between fitness and P3 amplitude and latency would be enhanced on iI trials compared to cI trials due to the Gratton effect. Previous research has found an effect of fitness on executive control functions (Kramer et al., 1999), so perhaps fitness would show a relationship with the specific executive control function of using information from the previous trial to perform a task, and that this effect would be detected using neuroelectric measures. Results demonstrated that greater fitness correlated with a lesser difference between P3 amplitude on iI and cI trials at Cz when instructed to focus on response speed. This demonstrates that greater fitness is related to more consistent allocation of attention to difficult trials regardless of the type of trial that precedes the difficult trial.

In terms of the expectancy effects that Gratton et al. (1992) described, this finding suggests that expectancies seem to be less of a factor for higher fit people on difficult cognitive tasks, which is contrary to the hypothesis that expectancies would enhance positive effects of fitness on P3 amplitude. Perhaps people who are more physically fit allocate greater attention to difficult tasks regardless of the noise level presented to them on the previous trial. Therefore, while the performance on difficult trials of less physically fit individuals may be inhibited following an easier trial that requires less attention, the performance of more physically fit individuals may be less impaired on these types of trials. In accordance with Gratton et al.'s (1992) explanation, this would suggest that more physically fit young adults devote more attention to later, focused-strategy processes while devoting less attention to automatic, parallel processing stages. Therefore, more physically fit individuals are more prepared for difficult trials following easier trials compared to less physically fit people regardless of task expectancies.

Overall, although two statistically significant results were detected, the majority of dependent neuroelectric measures seemed to be unaffected by fitness. Other researchers have found that fitness has less of an effect on the P3 in young adults compared to older adults (Hillman et al., 2004), and researchers who have found significant fitness effects on ERP components in young adults have compared groups of high- and low-fit participants (Themanson & Hillman, 2006), which improves the chance of finding a significant difference. In the current study, fitness was analyzed as a continuous variable, corresponding more closely to how fitness naturally exists, which may have made it more difficult to find significant effects of fitness.

Fitness and the Gratton Effect

In the present study, it was hypothesized that fitness would have a unique influence on the effects of noise expectancies on task performance that Gratton et al. (1992) discussed. Specifically, I predicted that fitness would correlate with faster, more accurate performance as well as greater P3 amplitude and shorter P3 latency on iI trials compared to cI trials due expectancies of noise level. This is the first study to look at a potential relationship between cardiorespiratory fitness and the Gratton effect. Previous researchers have found that increased fitness is beneficial to many higher-level cognitive processes including task switching (Hillman et al., 2006a), post-error behavioral modification (Themanson & Hillman, 2006), interference control, and stopping a pre-planned action (Kramer et al., 1999).

These findings support the importance of long-term commitment to physical exercise for maintaining and maximizing the efficiency of higher-level cognitive functions. However, although the results of the current study show a relationship between cardiovascular fitness and neuroelectric indices of the Gratton effect in one specific condition, it does not seem that fitness plays a pivotal role in the Gratton effect because the effect size was small and no effects were detected for behavioral indices of the Gratton effect. The present results suggest that if one is looking to improve his or her ability to use task expectancies based on previous information to perform better on difficult cognitive tasks, improving his or her level of cardiovascular fitness may not be an effective means by which to accomplish this. It is possible that there is a relationship between fitness and the Gratton effect that was not detected by the methodology of the current study, but this is unlikely because the fact that the Gratton effect was replicated demonstrates that the current method was sensitive enough to detect effects of task expectancies on cognitive performance, and should therefore be sensitive enough to detect a relationship between this effect and fitness if such a relationship existed.

Limitations

One limitation of the current study is its cross-sectional design, which prevents drawing conclusions about causation and may suggest that variables other than the ones that were measured are actually responsible for the effects that were found. However, data were collected on IQ, BMI, handedness, and several other demographic factors, and any correlations with these variables were taken into account when conducting the hierarchical regressions. Future studies could use a longitudinal design to deduce possible causal relationships between variables.

Another limitation of the present study is that all participants were young, healthy adults from the same geographical region, which may limit the generalizability of the results. Studies involving older adults, young children, or specifically-recruited high- or low-fit populations may find different results. Future studies could examine the effects of cardiorespiratory fitness on the Gratton effect in older adult populations or children to determine whether the abilities of young, healthy adults created a ceiling effect that masked the effect of fitness or if no relationship between these variables exists in any population.

Another point to note is that fact that the absence of predicted effects does not necessarily equate with the lack of an existing effect between variables. Although the present study utilized reliable measures, it is possible that there are existing fitness effects that were not able to be detected using these methods. Furthermore, with regard to the neuroelectric data, the absence of a difference in scalp potential does not equate with the absence of a difference in the generators in the brain because an infinite number of generator combinations could have produced the same effect at the scalp. However, the fact that fitness did not have an effect on the behavioral measures in the current study and only had a slight effect on neuroelectric measures strengthens the theory that fitness may not be important to predicting a heightened Gratton effect.

Conclusions

While the results of the current study did not strongly support the hypothesis of the relationship between cardiorespiratory fitness and the Gratton effect of noise expectancies in a young adult population, this study is important in that it assists other researchers in discovering the specific cognitive functions with which fitness may or may not be correlated and the populations of people to which increased fitness is most beneficial. Researchers are still attempting to understand the situations in which fitness does or does not affect cognitive performance and the neural mechanisms by which this effect may occur, and understanding which executive control functions appear to be most improved by increased fitness and those for which fitness may not be important helps other researchers in the field gain more insight into this problem.

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