

Running head: THE EFFECTS OF AEROBIC FITNESS AND ATHLETIC PARTICIPATION

The Effects of Aerobic Fitness and Athletic Participation on  
Executive Control Functioning and Motor Response Selection

Christine Cullen

Haverford College

## Abstract

The present study was conducted to analyze the effects of overall levels of physical fitness on executive control functioning, measured by accuracy and reaction time on an Erikson flankers task as well as EEG measures such as the P300. Lateralized readiness potentials were also studied to see if training in motor reactivity for athletic teams or physical fitness played any role in their onset or strength. Participants were found to be more accurate on trials where the target stimulus and flanking stimulus were congruent. These trials also elicited faster response times, shorter P300 latencies and shorter stimulus-locked LRP latencies. Athletic participation did not have a main effect on any measures of interest in this study, but participants' aerobic fitness levels (measured by their  $\text{VO}_2$  max) were found to be correlated with response times on congruent and incongruent trials. Greater interaction effects between electrode site and task congruency also emerged in lower-fit control subjects, but were not apparent in athletic populations. Although the aerobic fitness levels were shown to be statistically higher for athletes as opposed to non-athletes in this study, the overall homogeneity of this sample based on age and mental capacity may have dampened effects.

## The Effects of Aerobic Fitness and Athletic Participation on Executive Control Functioning and Motor Response Selection

Throughout history, philosophers and scientists have attempted to understand the connection between the mind and the body. In recent times, science has taken a more holistic approach by studying the interaction as opposed to the dichotomy of these two entities. Although it has been clear for quite some time that the brain, in particular the motor cortices, are able to control muscle movements and bodily functions, contemporary research has chosen to focus its efforts on trying to understand the impact that the physical body may have on the mind.

This study intends to further define the link between the body and the mind by investigating the effects of long-term physical fitness and athletic participation on the human cognitive processes that are involved in stimulus perception and response selection. This paper will analyze past research that has been useful in outlining the specific aspects of fitness and cognition that are strongly linked and the ways in which modern technology (e.g. electroencephalography) have been used to further tease apart the benefits that physical fitness can impart on the mind. This study hopes to add to this strain of research as well as explore new connections between these two entities that have been neglected in past research.

### *Exercise and the Mind*

Besides physically conditioning the body, the act of exercising has been shown to enhance numerous aspects of mental functioning, such as mood, self-esteem, and general psychological well being (Plante & Rodin, 1990). People who have participated in an aerobic exercise class for over six months have been shown to report lower levels of overall stress and more positive affect in their everyday life than people who did not participate in aerobic activities for extended periods of time (Dua & Hargreaves, 1992). There has also been some

research showing that exercise programs can benefit patients suffering from clinical depression (Khatri, Blumenthal, Babyak, Craighead, Herman, Baldewicz, Madden, Doraiswamy, Waugh & Krishnan, 2001). One account offered to explain these psychological benefits is that exercise enhances the levels of certain neurotransmitters, such as serotonin, norepinephrine and dopamine, which play a key role in mood regulation. In addition to these dispositional benefits, Potter and Keeling (2005) suggest that alterations in the level of these neurotransmitters may also play a key role in various aspects of cognitive functioning, such as enhancement of both working and long-term memory.

Exercise has also been shown to produce similar improvements in the cognitive functioning of animals by impacting the development and maintenance of the hippocampal region of the brain, which is responsible for visual/spatial memory (van Praag, Kempermann & Gage, 1999). This results in improved speeds at which these animals can perform new spatial and behavioral learning tasks (Churchill, Galvez, Colcombe, Swain, Kramer & Greenough, 2002). Hippocampal cell survival, cell proliferation and neurogenesis in adult mice have been found to be aided by unrestricted access to an exercise wheel, suggesting that such activity could have analogous effects in humans (van Praag, Kempermann & Gage, 1999).

Although the relatively highest level of cognitive processing for rodent subjects occurs in the hippocampal region, it is the frontal cortex, a structure whose cognitive abilities are not adequately represented in less complex animal subjects, that is responsible for the highest level of cognitive functioning in the human brains. In this way, parallels can be drawn between the hippocampal region of the rodent brain and the frontal lobes of the human brain. This may explain why there has not been overwhelming evidence showing exercise to be effective in enhancing performance on spatial memory tasks in human subjects, a cognitive ability that is

primarily mediated by the hippocampal region of the brain (Blumenthal and Madden, 1988; Tomporowski & Ellis, 1986).

### *The Frontal Lobes and Executive Control Functioning*

If it is true that exercise, as it has been hypothesized, has its largest effects on the most complex cognitive functions, then one should investigate the cognitive tasks that are performed by the human brain's frontal cortex. One of the most prominent areas of cognition localized in the frontal lobes of the human brain is executive control functioning (West, 1996). Executive control functions are controlled tasks that do not become automatic over time and require constant mediation by the central executor, such as coordination, inhibition, scheduling, planning and working memory (Colcombe & Kramer, 2003). These executive control functions require considerable amounts of attention, which is the general process of selective perception of sensory information. What a person directs their attention towards may be influenced by what the person perceives as being important. Cues may also help the person direct their attention to what they consider to be important. Selective attention tasks are often used to study an individual's executive functioning capacity by measuring that person's ability to attend to various sensory information. Tasks of this nature ask the participant to direct their attention to one feature of the stimulus and enact a motor response upon the presentation of this particular feature. The studies that have found the strongest impact of physical fitness have used reaction time tasks to measure effortful cognitive processes that require a considerable amount of attention (Chodzko-Zajko, 1991).

Aerobic exercise has been shown to be the most beneficial type of physical activity for the enhancement of executive control functioning (Churchill et al., 2002; Kramer & Willis, 2002). One of the reasons that aerobic as opposed to anaerobic activity in particular is thought to

better enhance executive control functioning may be through its ability to improve neurological functioning by increasing blood circulation within the brain (McAuley, Kramer & Colcombe, 2004). When performed regularly, aerobic exercise can lead to increases in aerobic fitness and one's capacity for oxygen intake, which, in turn, provide the brain with a more ample blood supply. When more blood is allowed to flow through the brain, more nutrients, such as glucose and oxygen, are able to be delivered to important structures that influence an individual's cognitive functioning. Kramer, Hahn, McAuley, Cohen, Banish, Harrison, Chason, Boileau, Bardell, Colcombe, and Vakil (2001) argue that frequent aerobic exercise plays a large role in the maintenance of cerebrovascular activity and cardiorespiratory functioning, which can in turn help to sustain cognitive aptitude as humans enter into old age.

#### *Aging, Fitness and Cognitive Functioning*

Neurological and cognitive declines related to perceptual, motor and executive control functioning are often associated with aging (Kramer & Willis, 2002). Studies examining the impact of exercise and physical fitness on elderly populations have the ability to provide much insight into the possible physical bases influencing the supposedly natural declines in cognitive functioning. The results of some of these studies have cast a doubt upon the belief that these declines are in fact natural, suggesting that their origins may rest in common drops in physical activity levels during the human lifespan. Through the use of functional magnetic resonance imaging (fMRI), McAuley et al. (2004) found that higher fit older individuals exhibited less gray matter loss and less loss of white matter tracts than their less fit counterparts. This study also examined the fMRI data taken before and after subjects' randomly selected participation in either an aerobic training program or non-aerobic control condition. Results suggested that participants in the aerobic training condition benefited from increased cardiovascular fitness levels, showing

less behavioral interference during a flankers task. The fMRI data from both studies suggest that aerobic fitness significantly moderates the trajectory of age related tissue loss (McAuley et al., 2004).

However, it is often difficult to assign causality when examining the relationship between exercise and cognition. It may be that the individuals' cognitive aptitude influences their decisions to engage in physical activity, rather than the opposite causal path. Hence, longitudinal studies that randomly assign individuals to fitness programs of varying aerobic and non-aerobic training can be especially helpful in examining the causal link between fitness and cognition.

By examining a sample of elderly individuals ranging in age between 60 and 75, Kramer et al. (2001) found that participants who completed a six month aerobic exercise program exhibited reaction time improvements on numerous executive functioning tasks compared to participants who exercised anaerobically (i.e., participated in a weight training program) for the same length of time. Studies have also suggested that older adults who participated in both aerobic and strength training showed greater improvements in executive function than those who received aerobic training alone (Colcombe & Kramer, 2003). Improvement in muscle tone from anaerobic conditioning is likely to influence the duration and intensity of aerobic exercise an individual is able to perform, indirectly contributing to individuals' levels of oxygen consumption.

A meta-analysis conducted by Colcombe and Kramer (2003) also found that fitness training had a robust impact on executive control functioning for older populations. This study also suggests that older adults who participated in fitness training for longer periods of time showed increased cognitive benefits when compared to those who participated in fitness programs for limited periods of time. However, not all studies have shown cognitive

improvements from participation in long-term exercise programs (Blumenthal, Emery, Madden, Schniebolk, Walsh-Riddle, George, McKee, Higginbotham, Cobb & Coleman, 1991).

Blumenthal et al. (1991) randomly assigned older participants (60 years of age and older) to either an aerobic fitness training program, a non-aerobic program, or no program. Although participants who participated in the aerobic training program for over 14 months reported improvements in psychiatric symptoms that were assessed by the Hopkins Symptom Checklist (SCL-90), they did not show any significant improvements on cognitive tasks to a greater degree than was exhibited in participants in either control group.

Although the aerobic fitness training program employed Blumenthal et al. (1991) did increase participants' aerobic capacity to levels of statistical significance, it may not have been able to raise participants' peak oxygen consumption to the necessary levels needed to induce improvements in cognitive functioning. Participants' peak oxygen consumption was measured by the  $VO_2$  max, which is the maximum amount of oxygen in milliliters that a person can use in one minute per kilogram of body weight. The failure of certain aerobic exercise conditions to translate into corresponding changes in participants' aerobic fitness levels may also explain why Kramer et al. (2001) did not find statistically significant improvement on certain executive control tasks upon completion of an aerobic training program. This could be due to unsystematic changes in all participants' oxygen uptake after completing either exercise protocol. The improvements in cardiovascular functioning (measured by oxygen uptake levels) may not have been large enough in magnitude to shorten the reaction times for certain tasks.

Also, Blumenthal and Madden (1988) showed that, although performance on a memory search task did not improve after participation in a twelve week jogging program, memory search performance was in fact related to initial fitness levels of the middle-aged male subjects.

This may further add to the idea that long term fitness levels have a larger impact on cognitive performance than relatively short intervals of aerobic training.

Age may account for some of the variance of participants' self selection into lifestyles that include widely varying levels of physical activity and cardiovascular fitness. The fitness levels of participants drawn from older populations are generally more homogeneous than those of younger populations. This may be due to the fact that older participants are often drawn from nursing homes or retirement communities and may not be representative of other elderly adults that live among the general population. Small increases in physical fitness from exercise protocols may therefore lead to a larger total percent increase in overall physical fitness for elderly population. Younger populations may need to increase their overall activity levels to a greater extent in order to reap similar cognitive benefits.

#### *Fitness and Non-Elderly Populations*

Although the relationship between fitness and cognition has been extensively studied and for the most part confirmed in elderly populations, research often fails to find effects in younger populations (Chodzjo-Zajko, 1991). Stones and Kozma (1989) examined whether spatial localization skills, measured by coding performance on the Digit Symbol and Symbol Digit tasks, are influenced by the age of participants and their physical fitness levels defined by daily caloric expenditure. Fitness level was found to mediate performance on the Symbol Digit task for the older population (with mean age of 62.9 years) but not for the younger, college-aged population (Stones & Kozma, 1989). Although increased physical fitness during young adulthood may not provide benefits to cognition as robust as those displayed in older populations, staying fit earlier in life may increase an individual's ability to stave off potential cognitive decline associated with inactivity in the latter years.

In order to find effects in younger populations, it seems necessary to study populations with more diverse levels of aerobic fitness. Due to cognitive decline in the later years of life, small differences in physical fitness bring about large difference in cognitive performance. Younger people in non-clinical populations are all in relatively good cognitive health, so it is only the largest discrepancies in physical fitness that reveal differences in cognitive aptitude.

High levels of physical fitness for members of younger populations are often brought upon by intense aerobic training that is often synonymous with athletic participation. However, self-selection based on an individual's pre-existing athletic skill set may influence decision whether to participate in activities that require such talents. For this reason, it may be difficult to assign causality when examining the relationship between motor/cognitive response time and athletic participation. Etnier, Salazar, Landers, Petruzzello, Han & Nowell (1997) found this type of self assignment as a threat to the validity of their meta-analysis. Despite this problem, Etnier et al. (1997) found that the largest effect size of regular exercise for older-middle aged populations (46-60 years) but also found that participants in their teens and twenties significantly benefited from ongoing participation in exercise activities. Many studies examining younger participants have used techniques other than simple reaction time measures to analyze cognitive changes due to ongoing, chronic exercise and acute exercise (i.e., a single instance of exercise before an experimental task).

### *EEG Measures*

Although exercise and physical fitness has been shown to have an influence on cognition in some populations, it is difficult to determine the precise components of the cognitive processes that are affected. One non-invasive procedure that can account for the particular mechanisms of cognitive functions and measure the enhancement of cognitive abilities in

humans resulting from higher fitness levels and acute bouts of exercise is the Electroencephalogram (EEG).

Electroencephalography (EEG) is a process of recording electrical signals from the scalp in order to measure different aspects of brain activity (Banich, 2004). Electrodes are placed on the scalp at sites that geographically correspond to particular regions of the brain where cognitive activity is thought to be taking place. Voltages representing the amount of activity at a particular site for a given point in time are continuously recorded by calculating the difference in charge between the active site and a relatively inactive reference location (most commonly, the mastoid bone). Electrodes are also placed around the eye muscles in order to control for blinking and other electrical signals such as muscle movements that may interfere with brain potentials.

Electroencephalography is often used to study continuous brain activity such as sleep patterns and aberrant brain functioning due to neurological disorders such as epilepsy. However, EEG can also be used to study the specific stimuli perception and response selection by way of event related potentials. Event related potentials (ERPs) record brain activity that is linked to the occurrence of an event, such as the presentation of a stimulus (Banich, 2004). When a stimulus is presented, dendritic fields in certain areas of the brain (depending on the characteristics of the stimulus) create a small dipole that can be measured by the electrodes. By placing these electrodes on the general area of the scalp over which the dipole occurs, one can record and analyze the waveforms generated at these sites. Components of the waveforms that occur after stimulus presentation are tagged and identified by both the approximate timeframe in which it is expected to occur and their positive or negative charge. The direction of an ERP's charge is derived from the orientation of the dipole within the brain tissue in regards to the active and reference site and is not behaviorally significant. However, the timeframe during which certain

identifiable peaks in the ERP waveform occur roughly correspond to various stages of the cognitive process; peaks occurring shortly after stimulus presentation are believed to represent more elementary sensory and perceptual processing whereas peaks occurring later in the waveform are thought to detect higher levels of cognitive functioning, such as decision-making and response selection. By systematically varying aspects of a stimulus, the timing and magnitude of ERP peaks can help researchers draw conclusions about the nature of the cognitive functioning.

Given that electrodes record activity from the scalp, ERP measurements are limited in their ability to detect cognitive activity occurring in deeper regions of the brain. However, it is possible to make inferences about the neural correlates of the hypothesized cognitive functioning that occurs during the presentation of a stimulus, especially in regions closer to the cortical surface of the brain (Rugg & Coles, 1996).

### *P300*

One of the most extensively studied components of an event related potential is called the P300. The P300 is a positive component of an ERP normally occurs from 250 to 400 ms after a stimulus is presented and produces a moderately large wave form anywhere from 10 to 20  $\mu$ V. This component can be elicited during tasks that require the participant to attend to a specific target stimulus and respond to that stimulus in a calculated fashion. Various obstacles may be presented, making the target stimulus more difficult to identify, in order to study changes in corresponding P300 measurements.

Latency and amplitude are the two important measurable aspects of the P300. The amplitude of the P300 can be defined as the voltage difference between the most positive peak within a set latency window and a pre-stimulus baseline measure. This aspect of the P300 is

thought to capture the amount of attention that is devoted to the task, and this can vary widely depending on the task's complexity and the arousal level of the subject (Kinoshita, Inoue, Maeda, Nakamura & Morita, 1996). The P300 is expected to be larger after the presentation of an infrequent or incongruent target stimulus than a frequently occurring stimulus, given more attention may be focused on attending and identifying the anomalous stimulus (Coles et al., 1996).

The latency of the P300 can be defined as the length of time between the initial presentation of the stimulus and the occurrence of the most positive peak amplitude within the given latency window. This aspect of the P300 is believed to measure the amount of time it takes for a person to recognize the stimulus (Coles et al., 1996). The P300 occurs before the motor response to the stimulus is enacted; however, it has been shown that the reaction time to a stimulus has a strong positive correlation with the latency and a strong negative correlation with the amplitude of the P300.

The Eriksen flankers task, which has often been used to evaluate executive control functioning, can be very useful in the generation of cognitive processes that elicit the P300 potential. Participants are presented with a row of letters or symbols and are asked to execute a response dependent upon the center stimulus. Congruent trials have a center letter/symbol that is flanked by a number of the same letter/symbol (e.g., SSSSS, >>>>>). In incongruent trials, the center letter/symbol is flanked by a letter/symbol that is different than itself (e.g., HSHHH, <<<<<). It has been shown that the response to the center stimuli is executed more quickly and accurately in congruent rather than incongruent trials (Hillman, Snook & Jerome, 2003). The surrounding stimuli in incongruent trials interfere with the perception of the center stimuli, resulting in premature activation of the incorrect response before the full appraisal of the stimuli

is complete. Activation of the incorrect and the correct response are in competition, delaying the execution of the correct response.

### *Lateralized Readiness Potentials*

Readiness potentials are slow, negative potentials that precede deliberate movement in the hands (Rinkenauer, Osman, Ulrich, Muller-Gethmann & Mattes, 2004). Larger readiness potentials occur in the side of the brain contralateral to the hand in which movement is intended. C3 is the electrode site positioned over the right hand area of the left primary motor cortex and C4 is the electrode site positioned over the left hand area of the right primary motor cortex. The lateralized readiness potential (LRP) measures the motor preparation for intentional movement in either the right or left hand (Coles et al., 1996). The difference between potentials generated by the asymmetrical activation of the different hemispheres of the motor cortex is calculated by averaging the mean amplitude difference intended for left hand movement (C4-C3) and mean amplitude difference intended for right hand movement (C3-C4). By averaging the amplitude differences to cancel out all hemispherical asymmetries due to non-motoric activity, a signal is created that reflects the strength and timing of response selection. The ability of the LRP to record the differential activation of each hand is especially useful when used to investigate individual aspects of decisions regarding the appropriate response to a particular stimulus.

One way to use the LRP to study differences in motor preparation is, by using two target stimuli, assigning one type of target stimulus a response that requires the motor activation of muscles in the right hand and the other stimulus a response that requires activation of the left hand. However, if information that is incongruent with the target stimulus is presented along with the target stimulus, the incorrect response has been shown to be partially activated before the correct response is acted upon (Coles et al., 1996). LRP waveforms for trials involving

incongruent stimuli exhibit a slight dip in the direction of the incorrect response, suggesting early partial activation of the incorrect response (Coles et al., 1996).

The Eriksen flankers task can also effectively measure lateralized readiness potentials (Coles et al., 1996; Gratton et al., 1988; Posthuma et al., 2002; Rinkenauer et al., 2004). This paradigm is expected to be especially effective for measuring possible differences in motor preparation that result from individual differences in athletic motor reactivity. Many sports in which this type of mental conditioning occurs (e.g., basketball, tennis, etc.) require the athlete to interpret incongruent stimuli that is present in different spatial locations. Given that the Eriksen flankers task presents incongruent information along with target stimulus in different locations rather than the same location (e.g., the Stroop task), motor preparation skills resulting from athletic participation can be more effectively measured.

The response-locked LRP and the stimulus-locked LRP are two different ways of calculating the LRP in order to measure different aspects of cognition in relation to the stimulus (Coles et al., 1996). The response-locked LRP interval measures the time interval between when the LRP is produced and when the motor response physically takes place (i.e., when the participant presses the correct button). This measures the amount of time needed to execute a response, which may depend more upon the innate characteristics of the participant rather than the characteristic of the task at hand (Hsieh & Liu, 2004).

On the other hand, the stimulus locked LRP interval measures the time between stimulus onset, which is used as the baseline measure, and the generation of the LRP. Hsieh and Liu (2004) found that the stimulus-locked LRP interval is associated with stimulus identification and response selection for that stimulus; the latency of the stimulus-locked peak can vary based on characteristics of the stimulus involved in the task as well as the internal traits of the participant.

*Exercise and ERPs*

*Exercise and the P300.* Non-EEG studies have lent support for the idea that of all cognitive processing occurring within the brain, exercise has been shown to have its largest effects on the brain's executive control functioning. Given that the P300 can measure this type of executive control functioning, it is logical to examine the role that aerobic exercise and overall aerobic fitness play in eliciting individual differences in the both the P300 latency and amplitude (Polich & Kok, 1995).

A number of studies have studied the effects of acute bouts of exercise on the P300 component. Research by Nakamura, Nishimoto, Akamatu, Takahashi & Maruyama (1999) elicited P300 amplitudes from an auditory oddball task (i.e., a task that asks participants to identify an anomalous audio stimulus present among a string of similar sounding audio stimuli). This study found that the P300 amplitudes of well trained joggers were significantly larger following an acute bout of jogging than before this bout of jogging took place. These increases in amplitude are believed to signify proportional increases in the amount of attention that is devoted to the task, in turn increasing the cognitive aptitude that is needed to identify the anomalous stimuli. However, this study failed to find significant differences between P300 latencies from tasks performed before and after the half hour jogging session. It may be possible that P300 latencies are unaffected by acute exercise, and are rather moderated by high aerobic fitness.

Hillman et al. (2003) also studied the impact of acute aerobic exercise on mental functioning. Twenty-two moderately active to highly active male and female college students completed the Eriksen flankers task both during a baseline session and after a 30 minute period of jogging. This study revealed main effect of exercise on the P300 amplitude, such that this amplitude was significantly higher for all conditions of the flankers task after acute exercise.

This study also found interaction effects between exercise and task condition (either neutral or incompatible flanker stimuli) for the P300 latency; stimulus congruency seemed to have a greater effect on P300 latencies for the baseline condition than after completion of an acute exercise task.

Magnie, Bermon, Martin, Madany-Lounis, Suisse, Muhammad and Dolisi (2000) looked at the impact of both overall aerobic fitness and acute aerobic exercise on the P300. This study examined ten competitive cyclists and ten sedentary (low-fit) control subjects and found that, for both groups, P300 amplitudes were larger and P300 latencies were shorter when performing an auditory oddball task after an acute exercise protocol than during a resting state. It is possible though that these effects were found due to practice effects of the auditory oddball task instead of the aerobic protocol; trials involving exercise were systematically conducted after trials recording for baseline P300 potentials. Also, this study controlled for the effects strict physiological arousal might have on P300 measures; after the exercise protocol, experimenters waited until subjects' temperatures and heart rates returned to baseline levels before administering the auditory oddball task.

Magnie et al. (2000) also looked at the effects participants' long-term levels of aerobic fitness had on their performance on the oddball task. However, there were no statistically significant differences between the aerobically conditioned cyclists and the low fit sedentary control subjects. However, Polich and Lardon (1997) found slightly different results. This study separated participants into a high and low fit group based on the amount and intensity of exercise in which they engage on an average week. Participants were given both an auditory and a visual oddball task, and the results showed that the individuals who engaged in relatively high amount

of intense physical activity on a regular basis had higher P300 amplitudes than participants who were relatively sedentary.

The effects of chronic exercise were also greater when participants were presented with a visual task rather than auditory task (Polich & Lardon, 1997). This could help to explain why differences in P300 amplitudes were not found in the Magnie et al. (2000) that used the auditory oddball task to elicit ERP measures. So although the auditory oddball task may be one of the more popular tasks used to study the P300 potential, it may be more beneficial to use more visual tasks (e.g., the Eriksen flankers task) in order to study and understand the relationship between fitness, P300 potentials and executive functioning.

However, Polich and Lardon (1997) did not find that physical fitness influenced P300 latencies. It is possible that differences in latencies did not arise due to the mean age of the subject pool, which was in the lower thirties. Other studies have suggested that differences in P300 latencies due to fitness level only emerge in older subjects (Dustman, Emmerson, Ruhling, Shearer, Steinhaus, Johnson, Bonekat & Shigeoka, 1990a; Dustman, Emmerson & Shearer, 1990b). Dustman et al. (1990) also found the mean latency of the P300 to be longer for older men of a low fitness level than older men of a high fitness level and the younger men of all fitness levels.

Polich and Lardon (1997) posit that some of the effects of long-term aerobic exercise on the P300 potential may originate from fundamental changes in the electrophysiological parameters employed in the experiment. This suggestion is supported by Dustman et al. (1990), who found the alpha bands at the Parietal (Pz) and Occipital (Oz) electrode sites of high fit subjects to be more abundant than those in low fit subjects. Alpha waves are indicative of a relaxed state of being and alpha wave suppression is often used to indicate the degree of brain

activation; for instance, depressed individuals have been found to exhibit greater alpha suppression over the frontal lobes (Banich, 2004). One way exercise may help maintain higher levels of alpha waves in the brain is by increasing the body's circulatory capacity and therefore increasing cerebral blood flow, which can be accomplished by aerobic training (Polich & Lardon, 1997).

In order to resolve conflicting findings in past literature about the effects of physical fitness on the P300, pilot data for the proposed study was collected and analyzed. This study divided participants into two groups based on the average hours exercised per week. It was found that college students reporting above the median number of hours exercised per week had significantly shorter P300 latencies than the college students whose number of hours exercised per week fell below the median. However, this study found no differences between participants' P300 amplitudes (Chaddock, 2005).

*Exercise and the LRP.* Motor response execution is a physical task, so it is logical that research should be conducted to determine whether there is a link between physical fitness and the ability to execute a motor response. It is also logical that people trained in physically reactive sports may have a superior ability to select a correct motor response, which may also be related to people's physical fitness level. Unfortunately, there has been virtually no research to date that examines the relationship between sheer physical fitness and the lateralized readiness potential. However, a small body of research focuses on highly trained athletes whose sports require high levels of motor reactivity. These studies examine motor responding and attentional flexibility by way of comparing the LRPs generated by both these skilled athletes and members of the general population. Although these studies have not touched upon the possibility that the augmented motor responses produced by these reactive-sport athletes may be due to specific physical

conditioning, it is possible that fitness levels can play a role in the enhancement of this cognitive ability.

Attentional flexibility is the ability to shift attention from one spatial location to another. Research on this cognitive ability has focused on athletes who participate in reactive sports, which require a refinement of this ability in order to successfully respond to movement and actions of other participants. One paradigm which is commonly used to study attentional flexibility employs warning stimuli to cue the location of an upcoming target stimulus. The majority of trials contain a warning stimulus that correctly indicate the location of the upcoming target stimulus. A minority of trials either contain a warning stimulus that incorrectly indicate the location of the upcoming target stimulus or did not contain a warning stimulus. According to this paradigm, one can improve their reaction time to the task by relying on the warning stimulus to correctly direct their attention to the target stimulus, which is defined as the attentional benefit of the warning stimulus. However, reaction time will suffer during the trials in which the warning stimulus miscues the location of the target stimulus, which is referred to as the attentional cost to attending to the warning stimulus.

This paradigm has been used to examine the reaction time and lateralized readiness potentials of elite table tennis players (Hung, Spalding, Santa Maria & Hatfield, 2004). One of the traits that have made these athletes successful in their sport is their high level of psychomotor reactivity. The results of the study suggest that table tennis players have superior reaction time and larger lateralized readiness potentials compared to controls, though they did not exhibit higher levels of attentional flexibility than controls. In other words, it appears that table tennis players and controls demonstrate similar cost/benefit ratios when responding to correctly and incorrectly cued locations of target stimuli in regards to reaction times and LRPs. However, this

study does show support for the idea that participation in activities that require superior motor responding may help condition preparatory motor cognition as indexed through the LRP.

Catiello and Umilta (1992) found that volleyball players were significantly faster than controls on incorrect trials that required the participant to direct their attention left, right or above the point of fixation. However, the athletes were not significantly faster than controls on incorrect trials that required a downward orientation of attention. This suggests that these athletes were able to perform better on tasks that used similar psychomotor skills as those that can be acquired during the practice of their sport. Therefore, it is posited that attentional flexibility and motor response preparation can improve with psychomotor practice.

Nougier, Ripoll, and Stein (1989) had both expert athletes and control subjects respond to stimuli presented in numerous horizontally arrayed locations. Overall, reaction time to stimuli presented further away from the center of the array was longer than that for stimuli near the middle; however, athletes showed a smaller discrepancy between the times generated by responding to both of these stimuli than did non-athletes. Responding to stimuli near the center of the display requires less attentional flexibility than the response need for stimuli on the periphery of the possible region in which stimuli could be presented; therefore, it is likely that the benefits from psychomotor practice is revealed as the task's level of difficulty increases. However, lateralized readiness potentials were not recorded in this study, so different effects may have emerged when examining both the response selection and response execution components of this measure.

Individuals who exhibit a higher level of aerobic conditioning may be able to enact a motor response more quickly due to superior physical fitness, but it is unclear whether these individuals are able to more quickly prepare that motor response. By studying the LRP of these

individuals in comparison to individuals who do not exhibit high levels of aerobic fitness, we may be able to begin answering this question.

### *Rationale and Hypotheses*

This study will further investigate the ways in which aerobic fitness resulting from various types of athletic participation may influence higher level cognitive functioning, such as executive control functioning and motor response preparation. By using participants who differ based on aerobic fitness level as well as in the amount of psychomotor training that is inherent in their sport, this study will be able to further classify exactly which aspects of physical fitness are responsible for changes in cognitive functioning.

Our sample will draw from three subject pools that are predicted to contain individuals that systematically vary on the dimensions of aerobic fitness and motor reactivity. One sample of subjects will be drawn from the Haverford College Men's Cross Country Team; it is anticipated that these participants will exhibit extremely high levels of aerobic fitness but will not have motor reactivity skills that significantly differ from a typical college-aged male. Another sample of subjects will be drawn from the Haverford College Men's Varsity Basketball Team; it is anticipated that these participants will have moderately-high to high levels of aerobic conditioning and will have superior motor reactivity skills due to the nature of their sport. The third and final sample of subjects will be non-athletic, low fit males drawn from the general student population of Haverford; these subjects are expected to have significantly lower levels of aerobic fitness than both the track athletes and the basketball players and average motor reactivity skills. The aerobic fitness levels of these participants will also be assessed apart from their specific athletic endeavors, and these measures will be used to further gauge the effects that cardiovascular functioning alone can play in cognitive enhancement.

These cognitive abilities will be measured by the reaction time to a choice decision task, the lateralized readiness potentials and the P300 potentials that are generated by this task. In order to preserve the parsimoniousness of the study's procedure, an Eriksen flankers task will be used to induce both P300 and readiness potentials. As well as being a clear choice for P300 elicitation, the Eriksen flankers task has been used in numerous studies in order to generate the lateralized readiness potential (Gratton et al., 1988; Posthuma et al., 2002; Rinckenauer et al., 2004).

Numerous hypotheses, based in part on past literature, will be presented in order to further expand the body of research in the field of exercise and cognition.

1) It is expected that aerobic fitness, which will be assessed by the individual's peak oxygen capacity (measured by the  $VO_2$  max) will vary according to specific athletic participation. Cross country runners are expected to have the highest mean  $VO_2$  max due to their extensive aerobic conditioning, basketball players are expected to have a mid to high mean  $VO_2$  max due to the aerobic training inherent in their sport and control subjects are expected to have a low mean  $VO_2$  max due to the lack of aerobic exercise in their lives.

2) High  $VO_2$  max is expected to be associated with shorter P300 latencies due to the effect physical fitness has on the amount of time needed to make an executive control decision. Cross country runners are also expected to have the shortest P300 latencies, followed by the basketball players and then the sedentary controls.

3) High  $VO_2$  max is expected to be associated with higher P300 amplitudes, which will indicate increased attentional devotion to the given task. Cross country runners are also expected to have the highest P300 amplitudes, followed by the basketball players and then the sedentary controls.

4) Although motor reactivity skill level may have a greater impact, The current study hypothesizes that participants exhibiting high motor reactivity skill level will not only be able to enact a correct response faster than subjects with a low motor reactivity skill level, but also that these subjects will have shorter stimulus locked and response-locked LRP latencies due to their superior motor preparation and response selection capabilities. Basketball players are expected to produce the largest LRPs due to their superior psychomotor skills and their moderate to high levels of aerobic fitness. Although the psychomotor skills of the cross country athletes and sedentary controls are not expected to significantly differ, the cross country athletes are expected to generate larger LRPs due to their superior cardiovascular function, which may allow more oxygen and nutrients to be carried to the relevant parts of the brain.

## Method

### *Participants*

Participants for this study were restricted to males attending Haverford between the ages of eighteen and twenty-three due to practical limitations. Males were chosen as opposed to females in order to prevent any confounds presented from greater hormonal fluctuations due to birth control or the menstrual cycle (Colcombe & Kramer, 2003). These participants were drawn from three different sectors of the Haverford population: members of the Haverford Men's Varsity Cross-Country team, members of the Haverford Men's Varsity Basketball team, and members of the non-athletic population. The defining characteristics of a person in the non-athletic population are that this person a) does not participate in varsity athletics, and b) does not exercise for over five hours per week (although one exception was made for a control subject who reported exercising on average eight hours per week).

Both Haverford Men's Varsity Cross-Country athletes and Haverford Men's Varsity Basketball players were recruited by an email invitation sent to all the members of each team that asked them to participate in the experiment. Non-athletic subjects were recruited by an email invitation sent to students who had signed up to take self-paced running, one of numerous classes that can be taken at Haverford in order to receive one of six gym credits that are required for graduation. Experimenters chose to sample non-athletic students from this population because this class is known among non-athletes as a popular alternative to participation in either Varsity or intramural sports in order to receive gym credit. All subjects were paid for their participation in the study, including the time spent running the required two miles for the Vo2 max measurement.

Thirty-one subjects were recruited for this study: 11 subjects represented the Haverford Men's Varsity Cross Country team, 10 subjects represented the Haverford Men's Varsity Basketball team and 10 subjects represented the non-athletic population of Haverford College. Participants ranged in age from 18 to 23 years of age with the median age being 20 years and the mean being 20.06 years of age ( $SD=1.34$ ).

Individuals were asked to complete a screening questionnaire before the commencement of this study in order to eliminate potential subjects whose habits or lifestyle may have presented confounds to the present study (See Appendix A). Individuals who have abnormal vision that cannot be corrected by glasses or contact lenses, a history of neurological problems, or a learning disability were excluded from the study.

Individuals who report cigarette smoking, heavy drinking or regular consumption legal or illegal substances known to affect the central nervous system were also excluded from this study. Finally, potential participants must indicate a willingness to either run or walk two miles in order

to be selected for the study. The cross country athletes, basketball players and control subjects chosen were screened so they match as closely as possible on overall dietary choices, sleep patterns, and alcohol consumption in order to further control for any variation in EEG recordings or reaction times that may result from these factors.

Lifestyle choices reported by subjects in the screening questionnaire, such as average number of hours of sleep per night, average number of alcoholic beverages consumed in a week, and how many meals eaten per day, were analyzed to determine whether subjects among the three sports groups significantly different on measures that may confound the present study. According to a one-way ANOVA, there were no significant differences in the average hours of sleep per night reported by cross-country runners ( $\underline{M}=7.68$ ,  $\underline{SD}=0.87$ ), basketball players ( $\underline{M}=7.50$ ,  $\underline{SD}=0.94$ ) and control subjects ( $\underline{M}=7.40$ ,  $\underline{SD}=0.94$ ), ( $F(2,28)<1$ ). A one-way ANOVA was also conducted to determine whether subjects differed in the number of alcoholic beverages that they consume in an average week. There were no significant differences among the runners ( $\underline{M}=1.41$ ,  $\underline{SD}=2.42$ ), basketball players ( $\underline{M}=3.50$ ,  $\underline{SD}=5.54$ ) and the controls ( $\underline{M}=2.70$ ,  $\underline{SD}=3.02$ ) in their consumption habits ( $F(2,28)<1$ ). Another one-way Analysis of Variance was conducted to determine if the subject groups significantly differed in the average number of hours that they receive per night, and once again, no significant difference was found (cross country= $3.00$ ,  $\underline{SD}=0.45$ , basketball= $3.00$ ,  $\underline{SD}=0.47$ , controls= $2.80$ ,  $\underline{SD}=0.75$ ), ( $F(2,28)<1$ ). Seeing as how subjects did not significantly differ on these aspects of their daily routine, experimenters can infer that these factors should not confound the quasi-experimental manipulation on which this study is based.

However, a one-way ANOVA showed that subjects did significantly differ on the average number of hours exercised per week according to their quasi-experimental group,

( $F(2,28)=26.80$ ,  $p<.001$ ). Post-hoc comparisons using the Tukey revealed that cross-country runners ( $M=12.18$ ,  $SD=4.85$ ) reported exercising significantly more hours per week than controls ( $M=2.70$ ,  $SD=2.79$ ), and that basketball players ( $M=18.90$ ,  $SD=6.56$ ) reported exercising more hours per week than both the controls and cross-country athletes. This discrepancy in the average number of hours exercised per week between the two athlete groups was unexpected and could be due to reporting errors; certain cross country runners and basketball players may have mistakenly reported only the number of hours they exercise outside of practice. It is likely that this is the case because many athletes (especially cross country runners) reported fewer hours exercised per week than the average number of hours their teams had scheduled practices. Even so, members of the two athletic teams did report exercising for more hours in an average week than control subjects.

### *VO<sub>2</sub> Max*

Before the commencement of the EEG recording and task presentation, each participant was responsible for providing experimenters with their fastest possible two mile time in order to calculate each individual's VO<sub>2</sub> Max. The VO<sub>2</sub> Max is defined as the maximum amount of oxygen in milliliters one can use in one minute per kilogram of body weight and this value has been shown to accurately measure one's aerobic fitness level (<http://www.brianmac.demon.co.uk/vo2max.htm>). People who have a higher VO<sub>2</sub> Max are able to exercise aerobically at a higher intensity level than people who have a lower VO<sub>2</sub> Max. Although the most precise measurement of the VO<sub>2</sub> Max involves the physical measurement of the amount of oxygen that is being taken into the body during aerobic training, there have been many other methods developed in order to calculate this fitness score in a more cost efficient manner. This study has opted to use a formula that uses a person's sex, weight and fastest

possible two-mile time to calculate the  $VO_2$  Max ( $VO_2$  Max =  $99.7 - [3.35 * \{2 \text{ mile time in decimal form}\}]$ ), <http://www.physicallytrained.com/fm21-20/physical-fitness-training/appendix-f.shtml>).

### *Task Procedure*

Participants were then asked to visit the laboratory. After signing the consent form for the study, subjects were fitted with an elastic cap (QuikCap) that contains the necessary electrodes to record the EEG data. To ensure the correct positioning of electrodes, measurements of the cap placement were taken from nasion to inion and from left to right. Event-related potentials were recorded by Ag/AgCl electrodes attached to the scalp at midline from frontal (Fz), vertex (Cz) and parietal (Pz) electrode sites, as well as over left and right motor cortices (C3 and C4 sites respectively). Due to technical problems, data from the Fz electrode site were not properly recorded for most participants and were not used in any further analyses. Two electrodes were also placed behind the ears, one on each mastoid bone, in order to serve as a reference. Electrodes were also attached to the side of each eye as well as above the left eye and below the left eye in order to measure blinking and other eye movement artifacts. The event related potentials were measured by the NuAmps amplifier at a sampling rate of 1000hz and a bandpass of 0.1-30hz (-3dB).

The participants were then asked to perform an Eriksen flankers task in order to elicit both P300 potentials and lateralized readiness potentials. This task was presented via E-Prime software on a desktop personal computer. Participants were asked to respond to a centrally presented target arrow as quickly as possible. If '<' was the target, participants were supposed to respond by pressing the 'G' key on the computer keyboard with their left index finger. If '>' was the target, participants were supposed to respond by pressing the 'H' key on the computer

keyboard with their right index finger. There was also two arrows of the same direction on both sides of the central target in the congruent condition (e.g., <<<<< and >>>>>). In the incongruent condition, there were two arrows pointing the opposite direction on both sides of the central arrow (e.g., <<<<< and >>>>>). These trial types were randomly intermixed when presented to subjects via E-Prime. Four blocks of 100 trials were presented. On each trial, the stimulus was presented for 150 ms followed by a blank screen, which would then be terminated by the subject's response. A trigger was set to mark the EEG record every time the stimulus was presented and the response enacted. Accuracy and reaction times on each trial were also recorded.

#### *Data Processing Procedure*

Before data analysis could continue, ERP data was re-referenced to the average of the two mastoid sites, and bipolar EOG channels were created. The effect of blinks was then reduced by using the Ocular Artifact Reduction program within the Neuroscan software.

For stimulus locked ERPs (i.e., P300 measures and stimulus-locked LRPs), the continuous waveforms for each participant were divided into epochs that ranged from 200 ms before the stimulus was presented to 600 ms after the stimulus was presented for each trial. Response-locked potentials required the continuous waveforms to be divided into epochs ranging from 700 ms before a motor response to the stimulus was executed to 300 ms after the response was executed. Epochs that overlapped with artifact-contaminated data were removed during this procedure. Epochs for congruent and incongruent trials were then averaged together separately to create congruent and incongruent waveforms for each subject.

The P300 was defined as the most positive-going peak within a 250 ms and 600 ms latency window following stimulus onset. The P300 amplitude was defined as the difference

(in  $\mu\text{V}$ ) between the pre-stimulus baseline measure and the P300 peak again computed separately at both the Cz and Pz electrode site. The P300 latency was defined as the time (in milliseconds) between the onset of the stimulus and the most positive point of the P300 event related potential at both the Cz and Pz electrode site (See Figure 1).

The first step in the process of calculating the response-locked LRP was to average the response-locked LRP epochs for trials that garnered a left-hand response and the trials elicited a right-hand response separately from the C3 electrode site and then again at the C4 electrode site. The averaged epoch for left-hand movement at C3 was then subtracted from the averaged epoch for left-hand movement at C4 in order to calculate the difference in brain activity between the left and right hemisphere when preparing and enacting a left-hand response. The averaged epoch for right-hand movement at C4 was then subtracted from the averaged epoch for right-hand movement at C3 in order to calculate the difference in brain activity between the left and right hemisphere when preparing and enacting a right-hand response (the subtraction is reversed due to contralateral hemispheric control of movement). These two waveforms were then averaged together to create a waveform representing asymmetrical activation of the motor cortices. The response-locked LRP was defined as the most negative-going peak occurring before a physical response to the stimulus (either a left or right hand button press) was enacted (See Figure 2).

The same process was repeated for the stimulus-locked LRP using the stimulus-locked LRP epochs. This procedure was also repeated twice, first using only congruent trials and again using only incongruent trials, to calculate two new averaged stimulus-locked LRP waveforms (See Figure 3). The stimulus-locked LRP was defined as the most negative-going peak following stimulus onset.

## Results

*VO<sub>2</sub> Max*

A one-way between subjects ANOVA was conducted to compare the mean VO<sub>2</sub> max values for subjects in the three main groups used in the study: varsity cross-country athletes ( $\underline{M}$ =67.41,  $\underline{SD}$ =1.41), varsity basketball players ( $\underline{M}$ =51.76,  $\underline{SD}$ =4.75), and relatively sedentary control subjects ( $\underline{M}$ =37.68,  $\underline{SD}$ =18.29). As expected, a significant effect of group on VO<sub>2</sub> max was found ( $\underline{F}(2,28)=20.11$ ,  $\underline{p}<.001$ ). Variances were found to be unequal using the Levene's Test for Equality of Variances, so the Dunnett's T3 was used for post-hoc comparisons. This test revealed that cross-country athletes had significantly higher VO<sub>2</sub> max values than both basketball players and control subjects, no significantly different VO<sub>2</sub> max values between the basketball players and control subjects. A less stringent post-hoc test, however, did show that VO<sub>2</sub> max values of basketball players were significantly higher than controls.

*Task Accuracy*

A 2x3 Analysis of Variance was calculated to test the effects of congruency of target stimulus (congruent and incongruent) and group membership (cross country, basketball and controls) on participants' task accuracy. Subjects whose percentage correct on incongruent trials was less than 80% were excluded from this analysis. These subjects, who all answered correctly on incongruent trials less than 15% of the time, are believed to have misunderstood the task and would jeopardize the validity of this analysis if included. Participants' mean percentage correct on congruent trials ( $\underline{M}$ =.983,  $\underline{SD}$ =.008) was found to be significantly higher than the percentage correct on incongruent trials ( $\underline{M}$ =.935,  $\underline{SD}$ =.011), ( $\underline{F}(1,18)=12.55$ ,  $\underline{MS}_e=.002$ ,  $\underline{p}=.003$ ). However, no significant differences in task accuracy for combined congruent and incongruent trials emerged among the runners ( $\underline{M}$ =.947,  $\underline{SD}$ =.012), basketball players ( $\underline{M}$ =.954,  $\underline{SD}$ =.011), and the

control subjects ( $\underline{M}=.976$ ,  $\underline{SD}=.011$ ), ( $\underline{F}(2,18)=1.67$ ,  $\underline{MS}_e=.002$ ,  $p>.05$ ). There was no significant interaction effect between the group and congruency, ( $\underline{F}(2,18)=1.38$ ,  $\underline{MS}_e=.002$ ,  $p>.05$ ).

### *Reaction Time*

A 2x3 Analysis of Variance was used to study the effects of congruency of target stimulus and group membership on participants' reaction time, or rather the period of time, measured in milliseconds, between first being presented with the stimuli and the produced response to the stimuli. Once again, subjects whose task accuracy on incongruent trials was less than 80% were excluded from this analysis for the same reasons as listed above. There was a significant effect of congruency ( $\underline{F}(1,18)=40.96$ ,  $\underline{MS}_e=2063.69$ ,  $p<.001$ ), such that participants' mean response time to congruent target stimuli ( $\underline{M}=333$ ,  $\underline{SD}=21.30$ ) was significantly faster than participants' response time to incongruent target stimuli ( $\underline{M}=423$ ,  $\underline{SD}=23.64$ ). A main effect of group membership on reaction time was also found ( $\underline{F}(2,18)=3.58$ ,  $\underline{MS}_e=18904.20$ ,  $p<.05$ ). Post-hoc testing using the Scheffe test showed that the mean reaction time of cross country runners ( $\underline{M}=311$ ,  $\underline{SD}=39.69$ ) was marginally significantly shorter than the reaction times of basketball players ( $\underline{M}=450$ ,  $\underline{SD}=34.37$ ). There was no significant difference between the control subjects ( $\underline{M}=374$ ,  $\underline{SD}=36.75$ ) and the other two groups. There were no significant interaction effects between the between subjects condition of group membership and the within subjects condition of trials either being congruent or incongruent, ( $\underline{F}(2,18)=.253$ ,  $\underline{MS}_e=2063.69$ ,  $p>.05$ ).

Pearson correlation coefficients were calculated to study the relationship between participants'  $\text{VO}_2$  max values and reaction time on both congruent trials and incongruent trials. A negative relationship bordering on statistical significance was found between  $\text{VO}_2$  max values and participants' reaction time on congruent trials ( $\underline{r}(28)=-.409$ ,  $p=.073$ ). A negative relationship also leaning towards statistical significance was found between  $\text{VO}_2$  max values and

participants' reaction time on incongruent trials ( $r(28)=-.396$ ,  $p=.084$ ). These correlations indicate a possible relationship between  $VO_2$  max and reaction time.

### *P300*

*Latency.* A 2x2x3 ANOVA was conducted to examine the hypothesized differences among P300 latencies (measured in milliseconds) according to congruency of target stimulus, electrode site (Cz and Pz) and group membership. All subjects with less than 80% correct on incongruent trials were excluded from this analysis, as well as one additional subject due to messy waveforms. There was a significant effect of stimulus congruency on P300 latency, such that the latencies for congruent trials ( $M=402$ ,  $SD=13.81$ ) were significantly shorter than P300 latencies for incongruent trials ( $M=448$ ,  $SD=15.71$ ), ( $F(2,17)=1.764$ ,  $MS_e=2022.44$ ,  $p<.001$ ). See Figure 1, which illustrates the main effect of congruency on P300 latency. However, there was no main effect of site, such that latencies recorded at the Cz electrode were not significantly different from latencies recorded at the Pz electrode, ( $F(2,17)<1$ ). There was also no significant differences among the average P300 latencies for the runners ( $M=417$ ,  $SD=25.32$ ), the basketball players ( $M=464$ ,  $SD=23.44$ ) and the controls ( $M=395$ ,  $SD=23.44$ ), ( $F(2,17)=2.23$ ,  $MS_e=15383.68$ ,  $p>.05$ ). However, there was a trend towards significance for the interaction effects of congruency, site and group ( $F(2,17)=2.70$ ,  $MS_e=2179.59$ ,  $p=.096$ ).

Each group was then analyzed independently by a simple effects analysis to determine which groups exhibited significant congruency and congruency/site interaction effects. According to 2x2 ANOVAs, the runners and basketball players only exhibited marginally significant main effects of congruency ( $F(1,5)=5.11$ ,  $MS_e=992.34$ ,  $p=.073$  and  $F(1,6)=4.45$ ,  $MS_e=2212.17$ ,  $p=.079$ , respectively). There was no significant interaction between electrode site and stimulus congruency for P300 latencies for the runners and the basketball players either

( $F(1,5)=1.34$ ,  $MS_e=1410.88$ ,  $p>.05$  and  $F(1,6)=0.94$ ,  $MS_e=3002.12$ ,  $p>.05$ , respectively). Control subjects, on the other hand, did exhibit a strongly significant main effect of congruency ( $F(1,6)=13.70$ ,  $MS_e=2691.12$ ,  $p=.01$ ), and were the only group whose interaction effect between site and congruency exhibited a trend towards significance ( $F(1,6)=4.80$ ,  $MS_e=1997.67$ ,  $p=.071$ ). Control subjects appeared to exhibit larger effects of congruency at the Cz electrode site (Congruent=347.29, SD=24.61, Incongruent=456.86, SD=34.55) than at the Pz electrode site (Congruent=369.86, SD=23.94, Incongruent=405.43, SD=28.63).

Overall, trial congruency did have an effect on P300 latencies, such that P300 latencies for congruent trials were significantly shorter than latencies for incongruent trials. The P300 latencies of control subjects were also found to be more heavily influenced by trial congruency than the P300 latencies of athletes, and were more specifically influenced by trial congruency at the Cz electrode site. See Table 1 for relevant P300 latency means and standard deviations.

Pearson correlation coefficients were calculated to study the relationship between participants'  $VO_2$  max values and P300 latencies at the Pz and Cz sites for both congruent trials and incongruent trials. No statistically significant correlation was found between participants'  $VO_2$  max values and participants' P300 latencies at the Cz site for either congruent trials ( $r(20)=-.065$ ,  $p>.05$ ) or incongruent trials ( $r(20)=-.328$ ,  $p>.05$ ). A statistically significant correlation was not found between participants'  $VO_2$  max values and participants' P300 latencies at the Pz site for either congruent trials ( $r(20)=-.132$ ,  $p>.05$ ) or incongruent trials ( $r(20)=-.139$ ,  $p>.05$ ).

*Amplitude.* A  $2 \times 2 \times 3$  ANOVA was used to study the differences among P300 amplitudes (measured in  $\mu V$ ) dependent on congruency of target stimulus, electrode site and athlete group. Once again, all subjects with less than 80% correct on incongruent trials were excluded from this analysis, as well as one additional subject due to messy waveforms. No significant differences

were found among the P300 amplitudes of the cross country runners ( $\underline{M}=14.71$ ,  $\underline{SD}=1.95$ ), basketball players ( $\underline{M}=13.85$ ,  $\underline{SD}=1.81$ ) and control subjects ( $\underline{M}=13.85$ ,  $\underline{SD}=1.81$ ), ( $\underline{F}(2,17)=0.68$ ,  $\underline{MS}_e=91.55$ ,  $p>.05$ ). Significant differences were not found between either the P300 amplitudes at the Cz Site and the Pz site, ( $\underline{F}(1,17)<1$ ), or the mean P300 amplitudes of the congruent trials and incongruent trials, ( $\underline{F}(1,17)<1$ ). There was only one significant interaction effect and that was the effect between stimulus congruency and electrode site, ( $\underline{F}(1,17)=9.56$ ,  $\underline{MS}_e=1.82$ ,  $p<.01$ ). It appears that there was no large difference between P300 amplitudes measured at the Pz ( $\underline{M}=14.17$ ,  $\underline{SD}=1.11$ ) and Cz ( $\underline{M}=14.41$ ,  $\underline{SD}=0.92$ ) sites for congruent trials, but that P300 amplitudes at the Cz site for incongruent trials ( $\underline{M}=14.79$ ,  $\underline{SD}=1.44$ ) were much larger than P300 amplitudes measured at the Pz site for incongruent trials ( $\underline{M}=13.16$ ,  $\underline{SD}=1.29$ ).

Pearson correlation coefficients were calculated to study the relationship between participants'  $\text{VO}_2$  max values and P300 amplitudes at the Pz and Cz sites for both congruent trials and incongruent trials. No statistically significant correlation was found between participants'  $\text{VO}_2$  max values and participants' P300 amplitudes at the Cz site for either congruent trials ( $\underline{r}(20)=.150$ ,  $p>.05$ ) or incongruent trials ( $\underline{r}(20)=.124$ ,  $p>.05$ ). A statistically significant correlation was not found between participants'  $\text{VO}_2$  max values and participants' P300 amplitudes at the Pz site for either congruent trials ( $\underline{r}(20)=.049$ ,  $p>.05$ ) or incongruent trials ( $\underline{r}(20)=-.048$ ,  $p>.05$ ).

#### *Lateralized Readiness Potentials*

*Response-Locked LRP.* A one-way, between subjects ANOVA was conducted on the response-locked LRP latency averages of participants in the three athletic groups used in this study: varsity cross country runners ( $\underline{M}=-74.90$ ,  $\underline{SD}=17.83$ ), varsity basketball players ( $\underline{M}=-80.70$ ,  $\underline{SD}=19.33$ ) and control subjects ( $\underline{M}=-80.56$ ,  $\underline{SD}=33.66$ ). Latency values are negative for

response-locked LRPs because it is measured as the amount of time before a response is selected. Two subjects were eliminated from this particular analysis because LRP peaks were not evident in their waveforms. Accuracy was not a factor in determining who to exclude from this analysis given that response-locked LRPs should not be dependent on whether or not the correct response was chosen; it only measures how long it took that participant to physically respond to their mental decision. No significant difference among these three groups was found ( $F(2,26)=0.183$ ,  $p>.05$ ).

A Pearson correlation coefficient was also computed to examine the relationship between participants'  $VO_2$  max values and response-locked LRP latencies. A weak correlation that was not significant was found between  $VO_2$  max values and response-locked LRP latencies ( $r(28)=.058$ ,  $p>.05$ ).

A one-factor, between subjects ANOVA was also conducted to see if there were any significant differences in response-locked LRP amplitude among the different athletic groups. Data from the same two subjects eliminated from the previous analysis were also excluded from the present analysis. The cross country runners ( $M=-7.52$ ,  $SD=4.64$ ), basketball players ( $M=-8.06$ ,  $SD=3.47$ ) and control subjects ( $M=-5.49$ ,  $SD=3.18$ ) were not found to significantly differ along this dimension ( $F(2,26)=1.162$ ,  $p>.05$ ). See Table 5 for a complete listing of means and standard errors.

A Pearson correlation coefficient was also calculated to investigate the relationship between participants'  $VO_2$  max values and response-locked LRP amplitudes. A weak correlation that was not significant was found between  $VO_2$  max values and response-locked LRP amplitudes ( $r(28)=-.146$ ,  $p>.05$ ).

*Stimulus-Locked LRP.* A 2x3 ANOVA was used to determine whether congruency of trial or group membership significantly influenced stimulus-locked LRP latencies. Subjects with compromised waveforms and those who responded correctly to less than 80% of the incongruent trials were excluded from this statistical test. A significant effect of congruency was found, such that stimulus-locked LRPs were generated in significantly less time in response to congruent target stimuli ( $M=368.17$ ,  $SD=21.74$ ) than in response to incongruent target stimuli ( $M=432.22$ ,  $SD=11.58$ ), ( $F(1,15)=10.24$ ,  $MS_e=3608.14$ ,  $p<.01$ ), (See Figure 3). There was no significant effect of group ( $X\text{-Country}=372$ ,  $SD=24.69$ ,  $Basketball=412$ ,  $SD=24.69$ ,  $Controls=417$ ,  $SD=24.67$ ), ( $F(2,15)=1.00$ ,  $MS_e=7317.05$ ,  $p>.05$ ) There was no interaction effect between group and congruency either ( $F(2,15)<1$ ).

A 2x3 ANOVA was also used to study whether congruency or group membership significantly influenced stimulus-locked LRP amplitudes No significant main effect of athlete group ( $F(1,15)=0.04$ ,  $MS_e=9.22$ ,  $p>.05$ ), congruency ( $F(2,15)=0.32$ ,  $MS_e=11.31$ ,  $p>.05$ ) or an interaction effect between group and congruency ( $F(2,15)=0.06$ ,  $MS_e=9.22$ ,  $p>.05$ ) were found among stimulus-locked LRP amplitudes. See Table 2 for a complete listing of means and standard errors.

## Discussion

Numerous results obtained from this research parallel which have been found in past literature. For the most part, however, predictions made about the efficacy of long-term fitness in enhancing the brain's executive control functions and the role coordinated motor reactivity plays in enhancing motor preparation were not supported by the evidence from this study.

*Aerobic Fitness and the VO<sub>2</sub> Max*

Overall predictions concerning the aerobic fitness level of participants sampled from predefined groups in Haverford's population were confirmed. Athletes were found to have significantly higher average oxygen capacity than non-athletes. Cross country runners were also shown to have higher average  $\text{VO}_2$  max values than both basketball players and control subjects, although average  $\text{VO}_2$  max values of basketball players were not found to be significantly higher than control subjects. The failure to find a significant difference between the aerobic capacity of basketball players and control subjects may stem from an inadequate sample size rather than actual similarities in aerobic fitness. Equal variances could not be assumed among the different athlete categories. Not surprisingly, control subjects had much higher variance among their  $\text{VO}_2$  max measures than did the runners or basketball players. This is most likely due to the fact that unlike the two groups actively involved in varsity athletics, control subjects do not have a uniform fitness routine that is characteristic of athletic team practices. A control subject's aerobic fitness level may be more dependent upon the amount of physical activity or exercise (a distinction that will be addressed later) in which that person participates in outside of an organized activity. Nevertheless, average  $\text{VO}_2$  max values were in the hypothesized direction across the three groups.

### *Congruency Effects*

In general, the majority of results obtained added support for the idea that distinguishing a target stimulus from incongruent flanking stimuli presented more of a challenge to participants regardless of group membership than trials in which target and flanking stimuli were compatible. These findings are consistent with those of past literature (Hillman, Snook & Jerome, 2003).

Task accuracy was found to be significantly better on congruent trials than on incongruent trials. This shows that subjects may have had more difficulty in selecting the correct

response during incongruent trials because the incongruent flanking stimuli interfered with their central executor. Incongruent trials also elicited significantly longer response times than congruent trials for all participants. This additional data lends support to the hypothesis that in all incongruent trials, an incorrect response is enacted before the participant chooses the correct response; inaccuracy on incongruent trials can be thought of as the result of carrying out the motor response of the incorrect decision before a person becomes aware of their error and is no longer able to correct for it (Hillman, Snook & Jerome, 2003).

P300 latencies were also subject to the congruency effect. Average P300 latencies were significantly longer for incongruent trials than for congruent trials (Refer to Figure 1). This also supports the proposition that a P300 takes more time to occur on incongruent trials because participants need additional time on incongruent trials to reverse an initial incorrect decision caused by the interfering flanking stimuli (Hillman, Snook & Jerome, 2003). However, the congruency condition of trials had no statistical effect on P300 amplitude. Congruency may have a more prominent effect on the amount of time it takes to perceive a stimulus (indexed by P300 latency) rather than the amount of attention devoted to its identification (indexed by P300 amplitude). Also, if the amplitude of the P300 peak measures only the amount of attention needed to decide upon the correct response (during correct trials) but not the attention devoted towards identifying the prematurely activated incorrect response during incongruent trials, there is no reason to think that the amount of attention needed to make the correct decision differs in either case.

Stimulus-locked lateralized readiness potentials occurred significantly earlier for participants during congruent as opposed to incongruent trials. This finding is similar in meaning to the congruency effect found in determining the latencies of P300 potentials; it supports the

idea that motor response decisions are quicker when a person does not have to filter out incongruent stimuli interfering with one's ability to choose the correct response. The response-locked LRP was not tested for congruency effects because this measurement has no established relation to the type of stimulus that elicits the readiness potentials; it simply describes a person's ability to elude a motor response in accordance with their executive decision.

#### *Athletic Group Membership Effects*

*Executive control and aerobic fitness level.* The majority of results did not support a direct link between increased aerobic fitness levels and improved performance on executive control tasks. Although the cross country runners, basketball players and control subjects had  $\dot{V}O_2$  max levels that were closely predicted by the amount of continuous aerobic training characteristic of their sports participation, the total aerobic fitness levels of these groups did not translate into better cognitive functioning. No main effect of group membership was found for task accuracy or P300 amplitude and latency.

However, a main effect of group membership was found for reaction time such that cross country athletes were marginally quicker than basketball players when enacting a motor response to the flankers task but that neither athlete group had reaction times significantly different from control subjects; for this reason, the study's hypothesis about athletic participation and its relationship with superior executive control functioning and motor responding was not supported. However, negative correlations between  $\dot{V}O_2$  max values and reaction time for both congruent and incongruent trials were marginally significant, suggesting that enhanced aerobic fitness does increase the overall speed in which executive control tasks are performed. This finding supports the research conducted by Etnier et al. (1997); although enhanced executive control functioning may occur in younger individuals, the effects size may be smaller than if the

same variance in fitness level was present in older populations. This may explain why some results did not reach full statistical significance.

However, interesting effects did emerge when examining the interaction effects between group membership, task congruency and electrode site for P300 latencies. A sample effects analysis showed that the cross country runners and basketball players did not exhibit this interaction effect and their P300 latencies were only marginally influenced by congruency. However, the non-athletes were significantly affected by the task congruency and exhibited a marginal interaction between electrode site and trial congruency. The effect of trial congruency was dampened at the PZ but appeared to be more prominent at the Cz site. The Cz electrode site is more closely located to the anterior cingulate cortex, which has been shown to be more sensitive to conflicting information (Hillman et al., 2003). Higher levels of physical fitness may help reduce the effect of conflicting information, particularly at this location of decision processing. However, a similar interaction effect occurred between electrode site and congruency for the P300 amplitude of all three participant groups, suggesting that physical fitness did not help mediate the congruency effect on attentional resources at the Cz site. The finding that control subjects did not significantly differ from athletes in P300 measures at the Pz site refutes the hypothesis by Dustman et al. (1990), who suggested that high-fit subjects exhibit increased alpha band abundance at the Pz site, resulting in superior performances on measures of EEG.

*Motor reactivity and the LRP.* An analysis of participants' stimulus-locked and response-locked lateralized readiness potentials has not shown any significant main or interaction effects of athletic group membership. Although differences were statistically insignificant, basketball players did exhibit the largest average stimulus-locked and response-locked LRP amplitudes, which falls in line with this study's hypothesis regarding LRP measures. It is possible that if

more subjects were employed in this study, effects would have approached statistical significance. If this were the case, one could imply that the motor reactivity skills that are practiced in sports and activities such as basketball could develop superior motor responding and may help condition preparatory motor cognition, which has shown to be the case for professional table tennis players (Hung, Spalding, Santa Maria & Hatfield, 2004).

### *Limitations*

One of main limitations of this study was the small sample size used to examine between subject effects. Normally, when objective cognitive measures such as reaction time and ERP data are used to study a specific phenomenon, a given effect will still reach statistical significance with the use of smaller sample sizes due to the lack of subjective interpretation needed for such tasks. However, data from many participants had to be eliminated from many analyses due to unexpected misunderstanding of task instructions, further decreasing sample sizes to levels that may not exhibit statistical significance. Equipment malfunction and high impedance values also made data collection difficult and resulted in the disqualification of select data from certain analyses, adding to the problem of low sample size. Although members of both athletic groups had homogeneous levels of physical fitness, control subjects varied greatly on this dimension. This variance may have compromised results that would have emerged if the controls were of a more uniform physical fitness level. One of the main elements used in selecting controls was their reported number of hours exercised per average week. However, like the athletes who exhibited some disagreement on what activities consisted of exercise, controls may not have accounted for physical activity that they did not see explicitly falling into that category, such as non-sports related activity or jobs that require substantial physical activity. Future research

should seek ways to better quantify physical activity when using this dimension as a screening technique.

Despite technical limitations to the study, some of the characteristics of the participants of this study may have lead to meaningful findings that lack statistical significance. Males may not exhibit as many cognitive benefits from increased aerobic fitness levels as females, which is a possible reason why many measures did not reach statistical significance (McAuley et al., 2004).

Many past studies have also not been successful in showing that increased physical fitness levels can produce beneficial effects for executive control functions in younger populations (Chodzjo-Zajko, 1991; Stones & Kozma, 1989). Cognitive advantages gained from leading an active lifestyle may not begin to emerge until the effects of aging begin to play a more prominent role in mental functioning, as demonstrated in the meta-analysis performed by Colcombe and Kramer (2003). Students obtained for this study are most likely close to their peak lifetime intellectual capacity; even if there were some cognitive effects of athletic participation, they were not large enough to emerge in statistical testing.

#### *Future Research and Implications*

This study has added to the ambiguities of past research that has sought to the links between physical fitness and cognitive functioning. Future research in this area could focus on using longitudinal studies in order to determine how and why physical fitness might influence cognition. However, as McAuley et al. (2004) notes, longitudinal studies involving random assignment of participants to experimental exercise conditions are difficult to conduct due to high drop out rates. Participants who complete a longitudinal study involving physical

conditioning may differ from participants who drop out in innate characteristics regarding their inclinations towards physical fitness, which creates an additional barrier to establishing causality.

One of the more interesting collection of results found in the present study was the interaction effect between athletic group membership, electrode site and task congruency. In future studies, P300 waveforms should be measured from more electrode sites (e.g., the Fz and Oz sites) in order to more closely determine the influence physical fitness has on select regions of the brain that may be responsible for executive control functioning. Physical fitness may bring forth different levels of change in cognitive performance for certain areas of the brain; by presenting stimuli in various sensory modalities, researchers could more easily determine which specialized areas of the brain exhibit the largest gains in executive control functioning from physical fitness and exercise. Functional Magnetic Resonance Imaging may also be helpful for researchers to better pinpoint regions of the brain that exhibit more elastic relationships between executive control functioning and physical fitness.

Future studies could utilize more heterogeneous samples to better examine the nuances that may influence the relationship between physical fitness and cognitive functioning. The interaction effects between age and physical fitness that influence various ERP measures should be more deeply investigated because of its possible implications for aging populations. Research should attempt to estimate cognitive gains according to the age of the individuals and their levels of physical activity, so exercise programs of appropriate intensity can be designed for individuals in different age categories to help stave off cognitive decline associated with a sedentary lifestyle as one ages. Further studying the links between physical fitness and cognitive functioning will help aging populations better maintain normal and healthy cognitive function throughout the latter years of their lives.



## References

- Banich, M. T. (2004). *Cognitive Neuroscience and Neuropsychology*. Boston, MA: Houghton Mifflin.
- Blumenthal, J. A., Emery, C. F., Madden, D. J., Schniebolk, S., Walsh-Riddle, M., George, L. K., McKee, D. C., Higginbotham, M. B., Cobb, F. R. & Coleman, R. E. (1991). Long-term effects of exercise on psychological functioning in older men and women. *Journal of Gerontology, 46(6)*, 352-361.
- Blumenthal, J. A. & Madden, D. J. (1988). Effects of aerobic exercise training, age, and physical fitness on memory-search performance. *Psychology and aging, 3(3)*, 280-285.
- Castiello, U. & Umilta, C. (1992). Orienting of attention in volleyball players. *International Journal of Sports Psychology, 23*, 301-310.
- Chaddock, L (2005). Unpublished Research Study.
- Chodzko-Zajko, W. J. (1991). Physical fitness, cognitive performance, and aging. *Medicine and Science in Sports and Exercise, 23(7)*, 868-873.
- Churchill, J. D., Galvez, R., Colcombe, S., Swain, R. A., Kramer, A. F., Greenough, W. T. (2002). Exercise, experience and the aging brain. *Neurobiology of Aging, 23(5)*, 941-955.
- Colcombe, S., Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14(2)*, 125-130.
- Coles, M. G., Smid, H. G., Scheffers, M. K. & Otten, L. J. (1996). Mental chronometry and the study of human information processing. In *Electrophysiology of Mind: Event-related Brain Potentials and Cognition*, Oxford: Oxford University Press.
- Dua, J. & Hargreaves, L. (1992). Effect of aerobic exercise on negative affect, positive affect, stress, and depression. *Perceptual and Motor Skills, 75(2)*, 355-361.

- Dustman, R. E., Emmerson, R. Y., Ruhling, R. O., Shearer, D. E., Steinhaus, L. A., Johnson, S. C., Bonekat, H. W. & Shigeoka, J. W. (1990a). Age and fitness effects on EEG, ERPs, visual sensitivity, and cognition. *Neurobiology of Aging, 11*, 193-200.
- Dustman, R. E., Emmerson R. Y. & Shearer, D. E. (1990b). Aerobic fitness may contribute to CNS health: Electrophysiological, visual, and neurocognitive evidence. *J Neuro Rehab, 4*, 241-254.
- Etnier, J. L., Salazar, W., Landers, D. M., Petruzzello, S. J., Han M. & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport and Exercise Psychology, 19*, 249-277.
- Gratton, G., Coles, M. G., Sirevaag, E. J., Eriksen, C. W. & Donchin, E. (1988). Pre- and Poststimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14(3)*, 331-344.
- Hillman, C. H., Snook, E. M. & Jerome, G. J. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology, 48*, 307-314.
- Hsieh, S. & Liu, L. (2004). The nature of switch cost: Task set configuration or carry-over effect? *Cognitive Brain Research, 22(2)*, 165-175.
- Hung, T. M., Spalding, T. W., Santa Maria, D. L. & Hatfield, B. D. (2004). Assessment of reactive motor performance with event-related brain potential: Attention processes in elite table tennis players. *Journal of Sport and Exercise Psychology, 26*, 317-337.
- Khatri, P., Blumenthal, J. A., Babyak, M. A., Craighead, W. E., Herman, S., Baldewicz, T., Madden, D. J., Doraiswamy, M., Waugh R. & Krishnan, K. R. (2001). Effects of exercise training on cognitive functioning among depressed older men and women. *Journal of Aging and Physical Activity, 9*, 43-57.

- Kinoshita, S., Inoue, M., Maeda, H., Nakamura, J. & Morita, K. (1996). Long-term patterns of change in ERPs across repeated measurements. *Physiology and Behavior*, *60*(4), 1087-1092.
- Kramer, A. F., Hahn, S., McAuley, E., Cohen, N. J., Banish, M. T., Harrison, C., Chason, J., Boileau, R. A., Bardell, L., Colcombe, A., & Vakil, E. (2001). Exercise, Aging, and Cognition: Healthy Body, Healthy Mind? In Human Factor Interventions for the Health Care of Older Adults
- Kramer, A. F. & Willis, S. L. (2002). Enhancing the cognitive vitality of older adults. *Current Directions in Psychological Science*, *11*(5), 173-177.
- Magnie, M. N., Bermon, S., Martin, F., Madany-Lounis, M., Suisse, G., Muhammad, W. & Dolisi, C. (2000). P300, N400, aerobic fitness, and maximal aerobic exercise. *Psychophysiology*, *37*, 369-377.
- McAuley, E., Kramer A. F. & Colcombe S. J. (2004). Cardiovascular fitness and neurocognitive function in older adults: A brief review. *Brain Behavior and Immunity*, *18*, 214-220.
- Nakamura, Y., Nishimoto, K., Akamatu, M., Takahashi, M. & Maruyama, A. (1999). The effect of jogging on P300 event related potentials. *Electromyogr. Clin. Neurophysiol.* *39*, 71-74.
- Nougier, V., Ripoll, H., and Stein, J. F. (1989). Orienting of attention with highly skilled athletes. *International Journal of Sport Psychology*, *20*(3), 205-223.
- Plante, T. G., Rodin, J. (1990). Physical fitness and enhanced psychological health. *Current Psychology: Research & Reviews*, *9*(1), 3-24.
- Polich J. & Kok, A. (1995). Cognitive and biological determinants of P300: An integrative review. *Biological Psychology*, *41*, 103-146.

- Polich, J., Lardon, M. T. (1997). P300 and long-term exercise. *Electroencephalography and Clinical Neurophysiology*, 103, 493-498.
- Posthuma, D., Mulder, E. J., Boomsma, D. I. & deGeus, E. J. (2002). Genetic analysis of IQ, processing speed and stimulus-response incongruency effects. *Biological Psychology*, 61, 157-182.
- Potter, D. & Keeling, D. (2005). Effects of moderate exercise and circadian rhythms on human memory. *Journal of Sport and Exercise Psychology*, 27(1), 117-125.
- Rinkenauer, G., Osman, A., Ulrich, R., Muller-Gethmann, H. & Mattes, S. (2004). On the locus of speed-accuracy trade-off in reaction time: inferences from the lateralized readiness potential. *Journal of Experimental Psychology*, 133(2), 261-282.
- Rugg, M. D. & Coles, M. G. (1996). The ERP and cognitive psychology: conceptual issues. In *Electrophysiology of Mind: Event-Related Brain Potentials and Cognition*, Oxford: Oxford University Press.
- Stones, M J., Kozma, A. (1989). Age, exercise and coding performance. *Psychology and Aging*, 4(2), 190-194.
- Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, 112, 297-324.
- Tomporowski, P. D. & Ellis, N. R. (1986). Effects of exercise on cognitive processes: A review. *Psychological Bulletin*, 99(3), 338-346.
- van Praag, H., Kempermann, G. & Gage, F. H. (1999). Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. *Nature and Neuroscience*, 2(3), 266-270.
- West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, 120(2), 272-292.

<http://www.brianmac.demon.co.uk/vo2max.htm>

<http://www.physicallytrained.com/fm21-20/physical-fitness-training/appendix-f.shtml>

## Appendix A:

The purpose of this questionnaire is to identify eligible participants for a study that will be conducted in coming weeks and months as part of a senior thesis project by Laura Chaddock, Christine Cullen, and LeeAnn Tanaka, under the supervision of Professor Rebecca Compton. By filling out this questionnaire, you are not committing yourself to participating in the thesis study. However, if your responses indicate that you are eligible, we may contact you to determine whether you would be willing to participate in the study.

If you feel uncomfortable answering any question, please feel free to leave it blank. Remember that your responses to the questionnaire are confidential. Only LeeAnn Tanaka will be able to view your responses linked to your name. (The other students and the professor will only have access to responses, not linked to names.) Once we have determined who is eligible for the study, LeeAnn will remove all names from our data records, ensuring confidentiality and anonymity of your responses in the permanent record.

Thank you for your time. We appreciate your help!

1) Gender:

Male

Female

2) Age :

3) Weight:

4) What is your graduation year?

2006

2007

2008

2009

Graduated

5) Would you be willing to run or walk 2.0 miles as fast as you can in exchange for payment?

Yes

No

Maybe

6) How often do you smoke cigarettes?

- Never
- 1-2 cigarettes a week
- 3-5 cigarettes a week
- 6 -10 cigarettes a week
- 1-2 packs a week
- 3-4 packs per week
- 5 or more packs a week

7) On average, how many alcoholic beverages do you drink per week?

8) On average, how many hours of sleep do you get per night?

9) Please rate your agreement with the following statement:

I have a regular sleeping pattern.

1	2	3	4	5	6	7
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Strongly Disagree				Strongly Agree		

10) How many meals do you typically eat per day?

11) Please rate your agreement with the following statement:

I consider my diet healthy and balanced.

1	2	3	4	5	6	7
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Strongly Disagree				Strongly Agree		

12) Do you currently play on or have you ever played on a collegiate varsity sports team?

- Yes
- No

13) If yes, what sport do / did you play?

14) Do you currently play on or have you ever played on an intramural / club sports team?

Yes       No

15) If yes, what sport do / did you play?

16) On average, how many hours per week do you exercise?

17) Do you consider yourself to be:

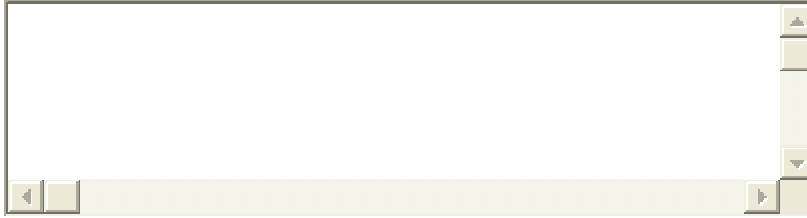
- left-handed
- right-handed
- ambidextrous (using both hands equally)

18) Please indicate whether any of the following statements apply to you. We have grouped these statements together to protect your privacy. If you check “yes” at the bottom of the list, no one will be able to tell the statement(s) to which you are responding.

- I have abnormal vision that is not corrected by glasses or contact lenses (e.g., color blindness, glaucoma, detached retina, etc.)
- I have a history of neurological problems, such as epilepsy (seizures), head injury, stroke, brain tumor, multiple sclerosis, etc.
- I regularly take medication that is known to affect the central nervous system. (Such medications could include anti-depressants, anti-anxiety medications, anti-psychotic drugs, drugs for epilepsy or other neurological disorders, etc.)
- I regularly consume non-medical substances that are known to affect the central nervous system (e.g., performance-enhancing drugs, substances such as marijuana, cocaine, heroin, ecstasy, etc.; do not include moderate use of alcohol, caffeine, or cigarettes).
- I have a learning disability.

- Yes, at least one of the above statements describes me.
- No, none of the above statements describes me.
- I am not sure whether any of the statements above describes me.

In the box below, you may explain your answer to the above question if you wish, but it is not necessary to do so.



Please submit your name and e-mail address below. We will use this contact information to get in touch with you if you are eligible to participate in the thesis study.

Name:

Email:

Thank you for completing this survey! If you have any questions, feel free to email Christine Cullen (ccullen@haverford.edu), Laura Chaddock (lchaddoc@haverford.edu) or LeeAnn Tanaka (ltanaka@haverford.edu).

[Click Here to Submit Your Survey!](#)

Table 1

*Mean P300 Latencies in Milliseconds (with Standard Errors) as a Function of Stimulus Congruency and Group Membership (excluding Subject 208 and All Subjects with Accuracy on Incongruent Trials Over 80%)*

	Group		
	X-Country	Basketball	Controls
Congruent	403(25.15)	445(23.28)	359(23.28)
Incongruent	432(28.60)	482(26.48)	431(26.48)

Table 2

*Mean Stimulus-Locked Lateralized Readiness Potential Amplitudes in  $\mu\text{V}$  (with Standard Errors) as a Function of Stimulus Congruency and Group Membership (excluding All Subjects with Accuracy on Incongruent Trials Over 80%)*

	Group			
	X-Country	Basketball	Controls	All Subjects
Overall	-4.90(0.97)	-7.05(0.97)	-6.01(0.97)	-5.99(0.56)
Congruency				
Congruent	-4.55(1.58)	-7.10(1.58)	-6.01(1.58)	-5.89(0.91)
Incongruent	-5.24(0.97)	-7.00(0.97)	-6.02(0.97)	-6.09(0.56)

Figure 1

*Averaged P300 waveforms of congruent trials (solid line) and incongruent trials (dashed line) for all participants (averages only include the P300s elicited from correct responses)*

Subject:  
EEG file: P300congruentCC.avg Recorded : 14:56:52 10-Feb-2006  
Rate - 1000 Hz, HPF - 0.1 Hz, LPF - 30 Hz, Notch - off

Neuroscan  
SCAN 4.3  
Printed : 19:15:56 13-Apr-2006

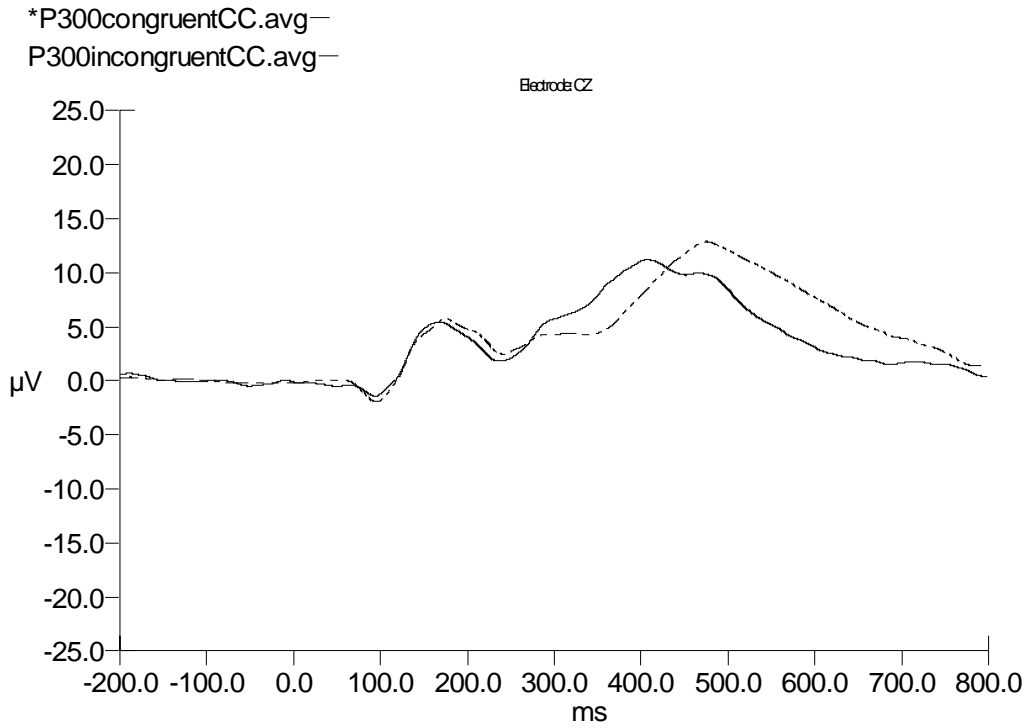


Figure 2

*Averaged response-locked LRP waveforms of all trials for all participants (0 milliseconds is the time of button press for participants)*

Subject:  
EEG file: RL\_LRP\_CC.avg Recorded : 18:27:19 08-Feb-2006  
Rate - 1000 Hz, HPF - 0.1 Hz, LPF - 30 Hz, Notch - off

Neuroscan  
SCAN 4.3  
Printed : 20:17:54 13-Apr-2006

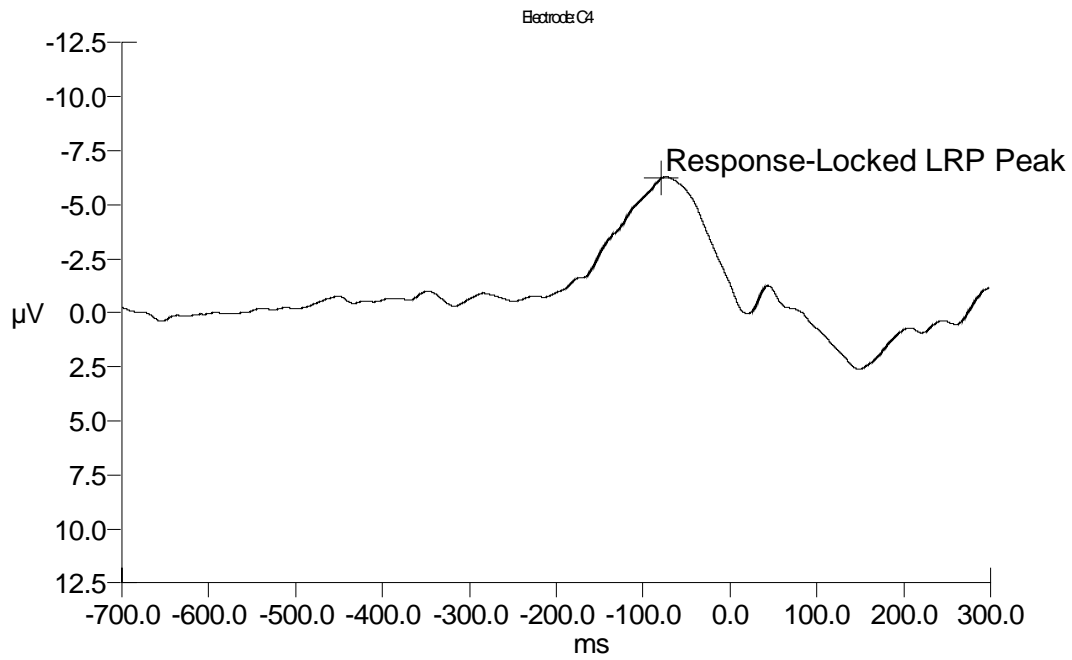


Figure 3

*Averaged stimulus-locked LRP waveforms of congruent trials (solid line) and incongruent trials (dashed line) for all participants*

Subject:  
EEG file: SL\_LRP\_congruentCC.avg Recorded : 18:27:19 08-Feb-2006  
Rate - 1000 Hz, HPF - 0.1 Hz, LPF - 30 Hz, Notch - off

Neuroscan  
SCAN 4.3  
Printed : 20:07:46 13-Apr-2006

