

Running Header: THE EFFECTS OF SPORT SPECIFIC EXERCISE ON COGNITION

The effects of sport specific exercise on cognition:

Investigating the P300 and the lateral readiness potential

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The effects of exercise on physical well-being have long been known. Recently investigations have examined whether exercise affects particular aspects of cognition but results are inconclusive, perhaps due to heterogeneous groups of athletes used. We studied two distinct groups of athletes (cross country runners and basketball players) as well as control non-athletes to examine possible effects of sport specific training, using the Flankers attentional task and measuring ERP components related to cognitive evaluation (P300) and motor preparation (LRP). We found no effects of sport specific training on the P300 or the LRP although athletic participation and fitness levels did indicate shorter and higher P300s as well as faster LRP and reaction times. We also found that athletic training yielded a smaller congruency effect on the Flankers task than for the sedentary control subjects.

The effects of specific exercise on cognition: Investigating the P300 and the lateral readiness potential

Exercise, while found to bring many physical health benefits (U.S. Department of Health and Human Services, 1996), has also been established to have cognitive benefits such as increased performance on memory tasks and screening out extraneous information (Tomporowski & Ellis, 1986). It has also been linked to improved cognitive performance in elderly individuals, indicating that exercise may help to slow the natural process of aging in the brain. Recently researchers have begun to investigate brain functioning during and after exercise to determine the particular processes involved in and affected by exercise.

*Benefits of Exercise*

Exercise has long been linked to positive health benefits. In 1996 the Surgeon General issued the first Report on Physical Activity and Health. This report stated that regular physical activity can create significant health benefits. The report also found that regular exercise can reduce the risk of developing heart disease, diabetes and high blood pressure. An example of the “moderate” activity recommended includes walking for 30 minutes every day, although the number of times per week has come down in the past few years (U.S. Department of Health and Human Services, 1996). More recently exercise, specifically cardiovascular fitness, has been linked to cognitive benefits as well as overall physical well-being, including positive effects on memory, reaction time, and learning. In general self-reports tell us that exercise improves one’s satisfaction with life, as well as one’s self-esteem. Regular exercise (3 times a week for 20 minutes at a time) is correlated with enhanced self-perceived quality of life as well (Laforge et al., 1999).

*Cognitive Benefits of Exercise*

Exercise is a broad term and can be broken down into two main types of physical activity: anaerobic and aerobic. Anaerobic exercise involves high physical work levels and an accumulation of lactic acid in the bloodstream. This accumulation leads to muscular fatigue which limits the duration of this type of activity. Some examples of this type of activity are weight lifting and running sprints. Aerobic exercise involves the presence of oxygen in the muscles which helps to free fatty acids into a source of energy. This type of activity is distinguished by the ability to maintain stamina and a constant level of exercise for an extended period of time. These two types of exercise have been found to have different effects on cognitive functioning (Tomporowski & Ellis, 1986).

During short duration, high intensity anaerobic exercise, speed on discrimination tasks was found to increase linearly. After completion of the exercise speed decreased significantly from the speed found while exercising. This type of exercise between 30 seconds and 2 minutes was found to significantly increase performance on memory tasks while this type of exercise for 5 to 10 minutes significantly decreased performance on memory tasks (Tomporowski & Ellis, 1986). This indicates that there is a ceiling for cognitive effects of exercise *during* the exercise.

Long duration aerobic exercise has been found to slightly facilitate free-recall memory tasks as well as significantly improving performance on vigilance signal-detection tasks (Tomporowski & Ellis, 1986) where those who had engaged in long duration aerobic exercise made fewer false-positive responses on a detection task. This type of exercise has also been shown to increase scores on Perception of Hidden Figures tasks as well. In the same review it was found that subjects who engaged in short duration-moderate intensity exercise (for an average time of 15 minutes) performed better on cognitive tasks while they were exercising with

their heart rate near 115 beats per minute but the performance fell back to baseline near 145 beats per minute and fell below those levels nearing 175 beats per minute. This finding is similar to the findings that cognitive performance drops if one exercises to the point of dehydration or exhaustion.

The most interesting feature of many of the studies in this review is that they found the more fit an individual was the better they could perform on cognitive tasks during physical activity than less fit individuals. This indicates a difference not only in acute exercise, short bouts of exercise prior to performing the task, but also possible chronic exercise effects, effects due to the participants' exercise habits in their every day lives. Hillman, Snook and Jerome (2003) also found improved ability on the Flankers task, a task where the subject must identify a central target within a string of symbols which can either be congruent or incongruent with the central target, after acute bouts of exercise for a group of moderately fit individuals. The majority of studies all looked at within subject differences after acute bouts of exercise and find significant improvements in cognitive abilities, but what about the effects of long-term exercise? Can working out daily for years permanently improve one's cognitive skills?

While there are indications that exercise may benefit people for years there do appear to be limits to the benefits that are associated with acute bouts of exercise. Kubesch et al. (2003) found that acute bouts of exercise (30 minutes of aerobic endurance) improved the cognitive abilities of clinically depressed patients as well, whereas there seemed to be no effect of exercise on cognitive ability for the healthy control subjects in this study. Specifically the depressed individuals showed improvement on their reaction time on the Stroop task and a GoNogo task, where the participants were asked to press a response key when the central fixation point disappeared from the screen while a black dot was still on the screen but told not to respond

when the central fixation remained on the screen with the black dot, but showed no improvement in reaction time on a task switching experiment, where the subject was presented with different stimuli all involving numbers and cued before each stimuli to make one of two types of decisions about the stimulus, or on the Flankers task which involves screening out extraneous information. This seems contradictory to the findings that exercise benefits all individuals on cognitive tasks. The researchers suggested that there may have been no effect on the controls for two reasons. First the healthy control subjects had no prior physical training, where as other studies look at populations of already active individuals. Secondly they suggest that since this group had no dysfunction (unlike the depressed group) they had no benefits to gain; since the controls had no deficit they had less area to improve upon. There may also have been a ceiling effect for the control subjects on these tasks.

Tomporowski's review (2003) found that although many researchers have found that exercise facilitates cognitive functioning, exercise that leads to dehydration can negatively affect information processing and memory. Lieberman et al. (2005) found that after intense exercise in the heat for 53 hours on U.S. Army officers caused not only sleep loss and dehydration but also negatively affected the participant's mood and cognitive functioning. They found that reaction time increased along with errors in a reaction time task, grammatical reasoning decreased and in a repeated acquisition task assessing motor learning, attention and memory there was an increase in incorrect responses as well as the time it took to complete. Clearly there are benefits to exercise but not if that exercise leads to dehydration and exhaustion.

#### *Benefits of Exercise in Aging Individuals*

Researchers took this line of inquiry a step further by looking at whether the positive effects of cardiovascular fitness can also help aging adults. The theory was that since a cognitive

decline is found in aging adults and can also be a factor in diseases that affect the elderly such as dementia and Alzheimer's that something that could benefit cognitive abilities (such as exercise) may be beneficial for that population. Kramer et al. (1999) found that for previously sedentary elderly adults those who were assigned to an aerobic work out group (walking) found significantly improved performance on task-switching tasks to measure the "cost" of switching between tasks, a stopping task to measure the ability to halt a pre-programmed response, and the response-compatibility task which looked at the ability to ignore irrelevant material. They did not find significant improvement on these tasks for those who had been assigned to the anaerobic group (stretching and toning). These measures are said to be measures of executive control functions which are management-like functions found to be localized in the frontal and pre-frontal cortex. They found no beneficial results for the aerobic or anaerobic group on tasks that were not tied to these executive functions. The results indicate that aerobic exercise may actually help to repair or restore the aging brain since the participants in this study were previously sedentary individuals who were put onto this exercise program for six months.

There have also been findings that cardiovascular fitness levels significantly mediated the age-related tissue loss in the white matter of the frontal, temporal and parietal lobes of the brains of aging adults (McAuley, Kramer & Colcombe, 2004). This finding indicates that elderly adults who engage in cardiovascular exercise may lose less white matter and consequently lose less of their cognitive abilities than their counterparts who do not exercise. Specifically these fit, elderly individuals would likely perform better on cognitive tasks that target these areas, such as executive control functions. Heyn, Abreu and Ottenbacher (2004) found in their meta-analysis that exercise increases fitness as well as cognitive function in elderly populations with dementia.

Not only does exercise seem to help the natural effects of aging in cognition it also appears to be useful when the cognitive declines are due to illness such as dementia as well. Similar results have been replicated in animal studies as well. Garza, Ha, Garcia, Chen and Russo-Neustadt (2003) found that in aging rats (22 months old) there were rapid (within 2 days) and sustainable (up to 20 days) responses to antidepressant treatments and exercise to the hippocampus, an area of the brain that deals with learning and memory functions. This indicates that the exercise for those aging rats positively influenced their memories and learning abilities.

### *The VO2 Max*

The VO2 max is often used in studies regarding exercise as a measure of a person's fitness. The VO2 max is defined as the maximum amount of oxygen in milliliters a person can use in one minute per kilogram of body weight. It has been consistently found that those who are more aerobically fit have a higher VO2 max (Palmer, 1995). It is possible to increase your VO2 max, by working out at the intensity so that your heart rate is between 65 and 85% of its maximum for at least 20 minutes 3-5 times a week for about 6 months. A person's VO2 max is difficult to improve! The VO2 max of a top athlete may drop to the VO2 max of an average individual if the top athlete stops training for a year. This means that athletes who work out on a regular basis will have higher a VO2 max than those who do not work out at all (Seiler, 1996). A high VO2 max of an individual has been correlated with high amounts of exercise by that individual (Palmer, 1995).

### *Electroencephalography and Event Related Potentials*

To better understand how exercise may effect cognition researchers have begun using electroencephalography (EEG). This is a non-invasive method of recording the brain's electrical activity. This is done by using metal electrodes positioned on the scalp above the area of the

brain that the researchers are interested in looking at. When a part of the brain is active it creates a dipole (a current with one positively charged end and one negatively charged end) which can be detected on the scalp through the electrodes. The assumption is made that if a part of the brain is active, then it is being used at that moment on the task at hand. By comparing the electrical signal on the scalp to an inactive site, such as the mastoid bone behind the ear, one can see the amount of electrical activity of the particular area of the brain.

Event related potentials (ERP) are recordings of the brain's activity linked with an event. By locking the timing of the electrical activity to stimuli researchers can investigate what parts of the brain are active at what times in response to a certain type of stimulus. In essence, an ERP can tell us "when" processes occur in our brains (Banich, 2004).

ERP components can be useful in ways that regular cognitive tasks and measuring reaction times cannot be. An ERP can inform us as to what part of the brain is active at a particular point in time after viewing a stimulus. This information can help us to discover what cognitive operations are going on and when they occur. Most importantly they are able to inform us of stages of processing, when different parts of the brain (the motor cortex or the sensory cortex for example) get involved. Different ERP components appear at different times after a stimulus and indicate different stages of processing. For example early components, those found within 100 ms of the stimulus, are linked to sensory processing while later components are linked to cognitive processing. By just looking at reaction times and accuracy on cognitive tasks it is possible to deduce only the information pertaining to speed of processing and motor reflex, but it is not possible to separate the two without using an ERP. By looking at an ERP it is possible to see where the latencies differ between or within subjects indicating how long it took

the subjects to assess the stimulus and also the amount of cognitive attention devoted to the task through amplitudes of the ERP components.

The main disadvantages of ERP components are that it is difficult to identify the source of the activity in the brain and that it is hard to detect the activation of cells that are parallel to the surface of the brain (Banich, 2004). It becomes difficult to identify the source of activity because there is no way of knowing precisely what area of the brain you are monitoring. Unlike MRI or PET scans there is no picture of the brain with an EEG. While you may know you are above the area of the motor cortex there signal may be coming from many places along the motor cortex. There are also some cells that are parallel to the surface of the brain, as opposed to most which are perpendicular to the surface. Those that are parallel are difficult to detect when a dipole occurs because the EEG may detect both poles changing rather than just one. This may be hard to read since charges could cancel each other, resulting in no electrical change to record.

### *The P300*

One well studied ERP component is the P300. The P300 is a positive component (positive going peak in an EEG) that appears between 300 and 800 ms post-stimulus (Coles, Smid, Scheffers & Otten, 1995). A sample P300 is illustrated in Figure 1. The amplitude of the P300 is understood to reflect the attention devoted to the task; a larger amplitude of the P300 is thought to indicate devotion of greater attentional resources. A longer latency of the P300 (from the onset of the stimuli to the peak of the P300) is correlated with a correct answer on a cognitive task while a short latency is understood to mean a faster evaluation of the stimuli (ie. the shorter the latency the faster the evaluation but the longer that latency is the more likely the answer is correct). The P300 is elicited during cognitive evaluations of a stimulus. From the time of the stimulus to about 100ms post-stimulus the ERP components are mostly driven by sensory

information. After this point the activation can also be stimulated by attention as well as higher functioning cognitive tasks (eg. memory and learning) (Banich, 2004). There is some confusion about what exactly the P300 is measuring, but researchers agree it does seem to be related to evaluation of the stimulus (measured by the latency of the P300), attention to the stimulus, and the updating of one's memory about the stimulus (measured by the amplitude of the P300 peak) (Banich, 2004). The subject must therefore be engaged in attending to the stimuli for the P300 to occur. Researchers tend to agree the P300 is related to attention and reflects the updating of one's memory. It is understood that once the P300 is elicited the processes that are necessary for the evaluation of the stimulus are complete (Coles et al, 1995). Fewer studies have investigated the amplitude of the P300 due to the interest in identifying the processes that occurred before the P300 and less interest in the amount of attention given to a task or stimuli.

Other studies measuring the P300 have used the Flankers task with encouraging results. In general longer P300 latencies have been associated with the incompatible patterns (Coles et al., 1985). This is likely due to the Flankers task being able to address individual's executive functioning abilities: filtering out unnecessary information and focusing on the necessary things. This is also an ideal task because the incongruent trials evoke a response at central (evoking the P300) and peripheral (motor responses evoking the LRP) levels (Posthuma et al., 2002; Rinkebaun et al., 2004). There seems to be a correlation in the findings between P300 latency and accuracy of response. In an early study, Coles, Gratton, Bashore, Eriksen and Donchin (1985) found that in trials with a given reaction time, higher accuracy was associated with shorter P300 latency. This contradicts more recent findings.

Since the P300 is thought to be related to cognitive functioning it would make sense for exercise to affect the P300 since exercise has been found to effect performance on cognitive

tasks. Polich and Lardon (1997) found that individuals who exercise more often (greater than 5 hours a week) had significantly increased P300 amplitudes compared to those individuals who engage in low amounts of exercise (less than 5 hours a week). This study finds that there is a difference between “high” and “low” exercisers. High exercisers seem to have higher P300 amplitudes, indicating more attention devoted to the task than those who exercise less often.

Nakamura et al. (1999) found that after 30 minutes of jogging athletes (specifically runners) had significantly increased P300 amplitudes than before exercising but no effect was found on the latency of the P300. This means that for athletes there is more attention paid to the task after exercising than before. The increased P300 amplitude seems to be one of the physiological improvement (in the brain) that previous researchers found through cognitive tasks. This appears to back up the prior research that found improved cognitive performance after exercise.

Magnié et al. (2000) found that after a session of acute exercise the high exercise group (cyclists) had significantly higher amplitudes as well as significantly decreased latencies in their P300 compared to before exercising. Magnié et al. (2000) also found, though, that the same was true for sedentary control subjects. In fact they found no significant difference between the athletes and the control subjects before or after exercising. This indicates that there is a consistent positive effect of exercise on cognitive abilities, for athletes and non-athletes alike.

Nakamura et al. (1999) did not use a sedentary control group so while their finding of increased P300 amplitudes after acute exercise appears to back up previous research they looked only at those who exercise fairly regularly and not at a group who does not. Magnié et al. (2000) indicates that exercise aided the high exercisers and the low exercisers in evaluating the stimulus faster and devoted more attention the task. Similarly, Hillman, Snook and Jerome (2003) found

that acute exercise resulted in significantly increased amplitudes of the P300 in their participants who varied in their physical activities. All three studies back up the idea that exercise positively affects all who do so.

These findings that acute exercise rather than chronic exercise affects the P300 are confusing when paired with what Polich and Lardon (1997) found. Magnié et al. (2000) and Hillman, Snook and Jerome (2003) suggest that there is no difference in the P300 latency or amplitude (before or after exercise) between those who exercise a lot and those who do not exercise, but rather that any exercise will positively affect one's cognitive abilities independent from whether they exercise regularly or not. This was seen by a significant increase in the amplitude, but not latency, of the P300. Polich and Lardon (1997) seem to have found that there is a difference in P300 amplitude between those who exercise regularly and those who do not. They did not look at the difference between their groups in relation to acute exercise. Polich and Lardon used two groups: high and low exercisers. Those in the high exercise group were not a homogenous sample, but rather a mix of athletes that may have been training in different ways and may actually have different levels of fitness. Magnié et al. (2000) used a homogenous group of high fit individuals: cyclists. Perhaps the mixture of athletes made the difference in effect for Polich and Lardon. It may be possible that aerobic fitness is not as important as anaerobic fitness, since Magnié et al. used cyclists who would be aerobically training. This leaves some questions regarding fitness and the P300. Might the *type* of training one is doing affect their cognitive abilities more than the amount (number of hours) they are training?

The latency of the P300 has been thought to reflect cognitive processing and classification speed and has been found to be affected by acute exercise. Hillman et al. (2003) found that exercise increased the amplitude of the P300 indicating that short bouts of exercise

may be beneficial to cognitive processes. They also found that shorter latency of the P300 for incompatible conditions of a Flankers task and opposite effect on the neutral condition, suggesting that effortful tasks may be more sensitive to positive effects of acute exercise compared to tasks that require less effort. Chaddock, Caris, Carp and Compton (unpublished data) found a shortened latency in their “high exercise” group (those who exercised more than 5 hours a week) than in their “low exercise” groups (those who exercised less than 5 hours a week) and no effect on the amplitude without any exercise manipulation. This difference in the P300 latency seems to suggest that those individuals in the “high exercise” group are faster at processing the stimuli than the “low exercise” group. The lack of difference in the P300 amplitude indicates that the “high” and “low” exercise groups dedicated the same amount of attention to the stimuli. The findings are clearly at odds with each other, finding effects of different components of the P300 due to exercise. For both of these studies there was the mixing of the types of “high” fit individuals used like in Polich and Lardon (1997) in the Chaddock et al. (unpublished data) study. Perhaps the reason the two found differing results indicates again that perhaps the *type* of exercise one is doing may be more influential than just the amount they are exercising.

To summarize, the previous literature on the effects of exercise on cognition has found a positive effect of exercise on cognition, with the exception of exercise to the point of dehydration. The literature looking at the effects of exercise on ERPs is less conclusive. While most data shows a positive effect of acute exercise on cognition (such as shortened latency of the P300 or increased amplitude of the P300) there are conflicting results on whether there is a greater effect for those who regularly exercise than for those who don't. Polich and Lardon (1997) found a greater effect for those subjects who exercised more than five hours a week than

for those who exercised less than five hours a week. Magnié et al. (2000) on the other hand found an effect of acute exercise on cognition for both athletes (cyclists) and non-athletes, but no effect between the two groups. Since Polich and Lardon (1997) used a heterogeneous group of high fit individuals it is possible that particular types of athletes may show a greater effect than other athletes as well as sedentary controls. The findings of the Tomporowski and Ellis review (1986) also found positive cognitive effects of exercise in a heterogeneous group of fit individuals. There is also conflicting literature on which aspect of the P300 (latency or amplitude) is affected by which types of exercise (acute or chronic). While most studies find a shorter P300 latencies after acute exercise the findings are much less conclusive when looking at chronic exercisers compared to sedentary controls. The other difficulty in teasing out an effect on amplitude or latency is that many of these studies use a mixed group of athletes. If either is a result of a particular type of training it is difficult to tease out which type of training affects what part of the P300.

#### *The Lateralized Readiness Potential*

The lateralized readiness potential (LRP) is another ERP but has not been as extensively studied as the P300. The LRP reflects the difference between the activation in the contralateral motor cortex of the hand you want to move and the activation of the motor cortex of the unused hand. The readiness potential (RP) begins equally large over both motor cortices but begins to lateralize (become larger in the contralateral cortex of the hand to be moved) before the motor response with a larger negative shift (amplitude) over the hemisphere contralateral to the response hand (Eimer, 1998). If one intends to use their right hand to press a key on the keyboard there will be a larger activation in the left motor cortex than in the right due to the contralateral nature of our motor cortices in human brains.

The LRP is an indication of a motor response, not of the participant's cognitive skills, unlike the P300 which is found to be an indication of cognitive abilities. This is also different from measuring reaction times (RT) of individuals. A RT is a response to a series of cognitive events which includes the activation of the motor cortex that lead to actual movement. The LRP on the other hand can help break down when the processes occur before the movement causing a RT, such as when the person decides which hand to use. The LRP usually occurs between 500 and 800 ms post-stimulus. The LRP taps processes solely in the motor cortex, reflecting the intention to move. The amplitude of the LRP indicates the strength of activation of the correct side of the brain to move the correct hand. The amplitude of the LRP is fairly small especially in comparison to the P300. It is therefore necessary to use a large number of single trials to calculate the average waveform. The latency of the LRP is generally broken down into smaller components to investigate, as explained below.

There have been two suggested methods of calculating the LRP. The most obvious one is the difference in electrical activation for left-handed responses (the amplitude in the contralateral minus the amplitude for the ipsilateral cortex) added to the difference for right-handed responses divided by 2 (taking the average). This method was used first by Coles (1989). The other method is the double subtraction method used first by De Jong, Wierda, Mulder and Mulder (1988). This method takes the difference for right-handed responses from the difference for left-handed responses.

$$\text{Average method: } [(C4-C3)_{\text{left hand}} + (C3-C4)_{\text{right hand}}]/2$$

$$\text{Double subtraction method: } (C4-C3)_{\text{left hand}} - (C3-C4)_{\text{right hand}}$$

The averaging method makes common sense. The double subtraction method is useful because any lateralized ERP activity that is present that does not have to do with the selection of a hand is

canceled out. For example if the ERP for the left motor cortex tends to be less positive than the ERP for the right motor cortex after the initial negative LRP peak for left as well as right handed responses that would be canceled out using the double subtraction method.

The LRP has been investigated in relation to motor inhibition. Van Boxtel, van der Molen, Jennings and Brunia (2001) found that the amplitude of the LRP in trials where the subjects had to inhibit their response was below LRP thresholds for movement (based on Gratton et al., 1988 and De Jong et al., 1990), although they did still occur. This indicates that even when the action does not take place (during the inhibited response) the subjects still had LRPs (as defined by Gratton et al., 1988 and De Jong et al., 1990). This means that the LRP is not dependent on movement but rather a precursor to that movement. LRPs are usually found using auditory oddball tasks (where the subject is told to indicate when they hear a tone differing in pitch than the others presented), but there have been a few studies that have looked at the LRP using the Flankers task (Gratton, Coles, Sirevaag, Eriksen, Charles & Donchin, 1988; Posthuma, Mulder, Boomsma & de Geus, 2002; Rinkenauer, Osman, Ulrich, Müller-Gethmann & Mattes, 2004). Due to the nature of the LRP (being a motor indicator, not an indicator of cognitive ability) any sort of perceptual motor task that requires a lateralized motor response will likely show the LRP.

There are two aspects to the latency of the LRP: the stimulus-locked LRP interval (S-LRP) and the response-locked LRP interval (LRP-R). The S-LRP is the latency between the stimulus and the apex of the LRP signal, indicating the time necessary to activate the correct cortex for motor movement. This indicates a link between the S-LRP and pre-motoric processes (see Figure 2). The LRP-R is the latency between the LRP apex and the motor response, indicating the time needed to execute the motor response once the correct motor cortex has been

activated. This indicates a link between the latency of the LRP-R and motor processes (see Figure 3). Many studies have found that variables such as stimulus redundancy, mental rotation and set size affect the latency of the S-LRP but not the LRP-R (Osman, Moore & Ulrich, 1995). Leuthold (2003) found that when primed with invalid information the S-LRP was lengthened, implying that since the S-LRP is linked to pre-motoric processes an invalid cue causes a longer latency of these processes indicating more time necessary to decide on the correct hand. If only the S-LRP is affected by invalid or incorrect information then we would infer that processing of that information was hindered, not the execution of the motor response itself. If stimuli only affect the pre-motor processes this indicates that the LRP-R is a locked chain of events that cannot be enhanced or quickened through practice; rather it's our reaction to the stimulus that can be improved so that our motor cortices recognize and respond to the stimulus more quickly. Other manipulations with an effect on the S-LRP include stimulus redundancy (Mordkoff et al., 1995), mental rotation, (Band and Miller, 1993) and set size (Ilan, 1996).

Stahl and Rammsayer (2004) studied how the LRP was affected by personality traits, particularly introversion and extraversion. They found that the S-LRP latency was shorter in introverts than extraverts, adding to the data which suggests this is the only part of the LRP latency that may differ due to personality differences. The same researchers found the opposite effect (a longer S-LRP latency) for extraverts (Rammsayer and Stahl, 2004). In a similar task they found that extraverts had shorter LRP-R latencies than introverts. These studies indicate that the more extraverted one is the longer their S-LRP indicating that it takes longer for extraverts than introverts to “choose a side” between their motor cortices, but that their motor response, indicated by the LRP-R, was faster than the introverts. This is the first evidence to suggest that there may be an effect of individual differences on central motor processes. These two studies

indicate an effect on the LRP due to extraversion, an aspect of personality. This suggests that there is an internal rather than external cause of effect on the latency of the LRP; the LRP may possibly be affected by individual differences as well. With the possibility of individual differences affecting the LRP it seems likely that individual training methods (sport-specific difference) may also affect the LRP. The studies by Rammsayer and Stahl (2004) are the first conflicting report of a possible effect on the LRP-R. Perhaps the LRP-R is a locked chain of events and cannot be enhanced or decreased but can vary significantly due to personality differences such as extraversion. There has not been much study as to what other internal (personality) differences or other individual differences may affect the LRP-R.

Is this the only possible effect on the latencies of the LRP, or can athletic training affect them as well? Only one study has looked at the effect of exercise on the amplitude of the LRP. Hung, Spalding, Maria and Hatfield (2004) looked at the reaction time and LRP of table tennis players and controls. They found that the table tennis players generated larger LRP amplitudes to prepare the corresponding hand to move than the controls. They found that when cued to a specific hand the table tennis players had a significantly greater difference between the cued hand and the un-cued hand (a larger amplitude LRP) than the controls as well as a faster RT to the cued hand when it was the correct choice. The table tennis players actually had a faster RT for *all* trials, even when it meant using the un-cued hand. This indicates that the sport specific training can in fact train one's brain to anticipate the correct hand to use. Since there is only one study in this sport-specific line of research it is difficult to draw conclusive views. It is necessary to further research into this field to better understand possible effects of specific training on cognition.

*Rational and Predictions for Current Study*

Based on the previous findings we predict that the higher fit an individual (defined by those with a higher VO<sub>2</sub> max) the shorter their latency and higher their amplitude on the P300 meaning the faster they will process the information and the more attention they will pay to the stimulus. We believe this will occur due to findings that indicate that those who are more fit will pay more attention to the stimuli, affecting the amplitude, and will also process the stimuli faster. Since there has been very little done in regards to sport specific exercise and cognition we propose looking at cross country runners, basketball players and a group of sedentary control subjects to better understand whether it is simply fitness (defined by the VO<sub>2</sub> max) that affects the P300 and stimulus processing or whether specific types of activity will affect the P300 differently. By looking at different types of athletes we hope to tease apart whether it is simply a general exercise phenomenon or whether the P300 is affected by specific types of exercise training.

The cross country runners, we assume, will run the fastest and therefore have the highest VO<sub>2</sub> max scores, followed by the basketball players and lastly the sedentary control subjects. If there is an overall effect of exercise, as measured by the VO<sub>2</sub> max, we should find a difference between groups regarding the latency and amplitude of the P300. We hypothesize that the cross country runners will have the highest VO<sub>2</sub> max, followed by the basketball players and then the control groups based on findings such as Palmer's (1995) which finds high fit individuals to have high VO<sub>2</sub> max scores. The cross country runners should also have the shortest latencies and highest amplitudes for their P300s (if, as hypothesized the P300 is correlated with the VO<sub>2</sub> max and not with specific types of exercise) due to their high aerobic training, followed by the

basketball players, who have aerobic training but less endurance training, and then the control group, with little to no athletic training.

The LRP is a measure of motor response rather than cognition so we predict that the basketball players will have the shortest S-LRP latency due to the hand-eye coordination requirements of their specific sport. We also predict that they will have the fastest reaction time due to their sport specific training. Since the runners will likely be more fit than the control group and therefore have better cognitive abilities we would expect them to have the next shortest latency (if, as we hypothesize, the S-LRP is also correlated with the VO<sub>2</sub> max and not only with specific types of exercise), following the basketball players, with the control group having the longest S-LRP latency. Due to the findings in the Hung et al. (2004) study we also predict the amplitude for the basketball players will be higher, due to sport specific exercise, followed by the runners and then the controls.

## Methods

### *Participants*

We recruited college aged males in three categories: 11 varsity cross country runners, 10 varsity basketball players and 10 sedentary control subjects defined as males who do not participate in any varsity, intramural or club sports in college and who report exercising less than 10 hours a week. We only used men for two reasons. The first is that most studies lump both men and women together but find slightly different effects for the two, so by looking solely at men we hoped to be able to get at the effects of the specific sports on cognition, rather than having to sift through gender differences. Secondly women's cognitive abilities may fluctuate due to their menstrual cycle. Including women may have had to involve accounting for their fluctuations in hormones due to where they were in their menstrual cycles as well.

All subjects were prescreened with an online questionnaire and we attempted to match the controls to the athletes on smoking and drinking habits and sleep patterns to the athletes. No participants reported that they smoked. On average the groups drank about the same amount of alcohol per week ( $M_{\text{runners}} = 1.41$ ,  $M_{\text{basketball}} = 3.5$ ,  $M_{\text{control}} = 2.7$  drinks). All subjects reported sleeping between 6 and 9 hours per night. The only criteria for the controls, once matched, was that they exercised 10 or fewer hours per week. On average controls reported exercising 2.7 hours a week, while the runners reported 11.7 and the basketball players reported 18.9 hours a week on average. We prescreened the subjects to exclude those with neurological history, medication that would affect the central nervous system or learning disabilities. All subjects were right-handed. All subjects were healthy and had normal or corrected to normal vision. We calculated the VO<sub>2</sub> max for each subject using their self-reported 2.0 mile using the 2.0 mile field test using the equation below. The cross country runners knew their 2.0 mile time, run during practice. We timed the basketball players on the indoor track and did the same for the control subjects who were able to make it. The rest of the control subjects ran the 2.0 miles on their own and timed themselves. The VO<sub>2</sub> max can be measured professionally by actually measuring the oxygen intake of a person while running but this procedure is very expensive and was not time efficient for our use. The VO<sub>2</sub> max can be estimated very well through equations such as the one below.

$$\text{VO}_2 \text{ max (for males)} = 99.7 - [3.35 \times (\text{2.0 mile run time in decimal form})] \text{ (Physically Trained, 2005)}$$

### *Stimulus/Materials*

*Prescreening questionnaire.* A prescreening questionnaire was sent out to all the students enrolled in self-paced running in the fall of 2005 for physical education credit as well as

distributed to peers of the researchers who are not involved in athletics. The questionnaire assessed diet, smoking and drinking habits, handedness and exercise habits and athletic involvement (See Appendix A).

*Flankers task.* The Flankers task was presented on a Dell Dimension desktop PC running E-Prime software. Stimuli consisted of congruent “>>>>>” or “<<<<<” and incongruent “>><>>” or “<<><<” patterns which were presented in black writing on a white background. Participants were asked to indicate the center target of each sequence by pressing either the “g” key with their left hand when the central target is a left pointing arrow (<) or the “h” key with their right hand when the central target is a right pointing arrow (>) on the computer keyboard. The task included a practice block with 8 trials as well as 4 blocks of 100 trials (25 of each pattern and randomized by the computer) each with brief breaks between blocks. There was a prime screen with a cross in the middle presented for 500 ms prior to each stimulus. The stimulus image was then shown for 150 ms and was followed by a blank black screen which was terminated by the participant’s response. After the response there was another blank screen presented for 500 ms before start of the next trial.

*Electrophysiological recordings.* Electroencephalographic (EEG) activity was recorded during the Flankers task using an elastic cap (Quik-Caps) with sintered Ag/AgCl electrodes. The cap was aligned using measurements from the nasion and theinion. Left-right alignment was confirmed by ensuring that the midline electrodes are positioned halfway between the ears. Recordings were made continuously from the midparietal sites Cz, Pz and from C3 and C4 (over the left and right motor cortex). Data were referenced on-line to the right mastoid (A2). Data were later re-referenced to the average of the left (A1) and right (A2) mastoids. Electro-oculographic activity (EOG) was recorded vertically and horizontally with Ag/AgCl electrodes

above and below the left eye and at both temples. Impedances ranged from  $0\text{k}\Omega$  to  $430\text{k}\Omega$  with a mean of  $25.91\text{k}\Omega$ . Signals were amplified by a NuAmps amplifier controlled by Neuroscan software with a sampling rate of  $1000\text{ Hz}$  and filtering was set with a band pass of  $0.1\text{-}30\text{ Hz}$ .

Triggers were sent from the task computer to mark the onset of each stimulus and the time the response was made by the participant. These time stamps were used to identify and create the ERP components (the P300 and LRP) through the signal averaging process for each participant. . Large portions of the EEG record with large non-blink artifacts were manually excluded by hand first by the researchers. The process of defining the ERP components began by re-referencing the waves to the average of the A1 and A2 sites. The effect of blinks was then reduced off-line by using the Neuroscan software's algorithm for ocular artifact reduction. The files were divided in to epochs around the stimulus markers from  $-200\text{ ms}$  to  $600\text{ ms}$  to create the window for the P300 and S-LRP. Epochs were created for the LRP-R around the stimulus markers from  $-700$  to  $300$  where time 0 is the subject's response. The files were then corrected to baseline measures, had any remaining epochs with artifacts deleted, using a  $\pm 50\text{ microvolt}$  threshold, and then had all the remaining epochs averaged to create 2 average P300 wave forms for each subject, one with incongruent trials and the other with congruent trials. During this step six LRP averages were created, 2 (one for left handed responses and the other for right handed responses) based on the response marker (only including trials where the subject answered correctly) and the other 4 (two left and two for right handed responses) based on the stimulus marker, making one average for each hand for congruent trials and also for incongruent trials. To obtain the actual LRP from this data we used the same method as Coles (1989), the averaging method, taking the difference for right-handed trials (C3-C4) added to the difference for the left-handed trials (C4-C3) and averaged (divided by 2). This was done separately for each subject

and congruency condition. The resulting waveform represented the S-LRP, when time 0 was the stimulus onset and LRP-R where time 0 was the response made by the subject. The S-LRP latency indicated the time between stimulus onset and the moment of lateralization between the hemispheres. The LRP-R latency indicated the time between lateralization and the subject's motor response. For the P300 and both LRP waveforms all epochs were used from each subject to average into a grand waveform for the congruent and incongruent trials. The LRP peaks represented the degree of contralateral motor cortex activation while the P300 peak represented the degree of attention paid to the stimulus.

#### Analysis/Results

Based on previous research we predicted fitness levels would correlate with shorter P300 latencies and higher P300 amplitudes. Specifically that runners would have the shortest P300 latency and highest P300 amplitude (assuming that they would be the most fit) followed by basketball players and then by the control subjects. We also predicted that for the LRP measure basketball players would have the shortest S-LRP latency, due to their sport specific training, followed by the runners and lastly the controls, assuming that the LRP is also connected to fitness level. We also predicted that the basketball players would have the fastest reaction times due to their training followed by the runners and then the control subjects, assuming that the LRP and reaction time are connect.

#### *VO2 max*

We ran a one way ANOVA to compare the average VO2 max values for each group (three levels: runners, basketball players and controls). There was a significant effect of group on the VO2max scores ( $F(2, 30) = 20.11, p < 0.001$ ), with the track runners having the highest VO2 max scores and the controls having the lowest ( $M_{\text{runner}} = 67.41, M_{\text{basketball}} = 51.76, M_{\text{control}} =$

37.68). We ran a Tukey HSD post hoc analysis and found that all three means were significantly different from each other. The runners were in fact “most fit” with the highest VO2 max scores, followed by the basketball players and then the controls, as we predicted.

### *P300*

We ran a 3x2x2, group (three levels: runners, basketball players and controls) by site (two levels: CZ and PZ) by congruency (two levels: congruent and incongruent), analysis on the amplitude of the P300. We excluded 10 subjects whose accuracy was below 80% on the incongruent trials indicating they had performed the task incorrectly due to misunderstanding the instructions and a basketball subject whose waveforms were too messy to observe a distinguishable P300. These subjects were excluded for all P300 analyses. We found an unexpected interaction effect of congruency by site ( $F(1, 20) = 9.561, p < .01$ ). The means (see Table 1) indicate that the amplitude was lower for the incongruent trials at PZ than at CZ. The means by group showed the trend we hypothesized (see means in Table 2) with the runners having the highest amplitudes followed by the basketball players and then the controls in the congruent trials, but this was not near significance ( $F(2,17) < 1$ ). In the incongruent conditions the Runners still had the highest amplitudes but they were followed by the controls and then the basketball players. The congruency difference (amplitude difference between the incongruent and congruent trials) was largest for the controls, followed by the runners and then the basketball players.

We ran a 3x2x2 (group by site by congruency) ANOVA for the latency of the P300. Here we found a main effect of congruency ( $M_{congruent} = 402$  ms,  $M_{incongruent} = 448$  ms) with the subjects' latency being longer on the incongruent trials than the congruent ones ( $F(1, 17) = 21.17, p < 0.001$ ) (see Figure 1) and a marginally significant 3-way interaction trend (group by

site by congruency) ( $F(2,17) = 2.698, p < .1$ ). We then ran a post hoc analysis by breaking the three-way interaction down by group and using a 2x2 (congruency by site) repeated measures ANOVA for each group level. For the runners and the basketball players we found marginal congruency effects ( $F(1,5) = 5.114, p < 0.080$ ;  $F(1, 6) = 4.450, p < 0.080$  respectively) while for the controls we found a large congruency effect *and* an interaction trend of congruency by site ( $F(1, 6) = 13.699, p < 0.010$ ;  $F(1, 6) = 4.797, p < 0.080$ ). This congruency by site interaction for the controls likely was the cause of the three-way interaction found in the 3x2x2 P300 latency ANOVA. Based on this post hoc analysis the controls appeared to have the greatest congruency effect, indicating that they are more affected by the incongruent information than the runners or the basketball players (seen in Figure 4). This was confirmed by the highly significant congruency effect for the controls as compared to the effect for the runners and basketball players. The effects of congruency (the difference between the congruent and incongruent trials) is not only greater for the controls, but was more pronounced for the controls at the CZ site.

We then ran a 2x2x2 (congruency by site by athlete) mixed ANOVA for the P300 latency, separating the subjects into either the “athlete” group (including the runners and basketball players) or the “non-athlete” group (containing just the control subjects). We found a significant effect of congruency ( $F(1, 18) = 26.682, p < 0.001$ ) as we predicted. We also found a marginal effect of congruency by athlete ( $F(1, 18) = 3.591, p < 0.080$ ). By looking at Figure 5 we see that while the non-athletes (controls) were faster for both congruent and incongruent trials the controls had a greater effect of congruency, that is to say that the difference between the incongruent and congruent trials was greater for the controls, as we found previously. Lastly we found a marginal effect of congruency by site ( $F(1, 18) = 3.084, p < 0.10$ ). The congruency

difference was greater at site CZ than at site PZ, with both of them showing the expected trend of a longer latency for incongruent than congruent trials.

We ran a Pearson bivariate correlation test comparing the participants' VO2 max to their P300 amplitudes and latencies. We found no correlations to the VO2 max and the P300 components but did find that the latencies and amplitudes (for congruent and incongruent trials at CZ and PZ) were intercorrelated with one another ( $r$  ranged from 0.000 to 0.011) indicating that although these values were significantly different between groups they are still correlated and therefore consistent measures of the P300. Give some  $r$  values to let them know how strong/weak the patterns were.

### *LRP*

*LRP-R.* We ran a one way ANOVA to compare the means between groups (three levels: runners, basketball players and controls) for the latency of the LRP-R. We excluded one runner and one control subject due to unreliable waveforms and they were omitted for all LRP analyses. There was no significant effect of group found ( $F(2, 27) < 1$ ). The means were also not in the anticipated direction ( $M_{\text{runner}} = -75\text{ms}$ ,  $M_{\text{basketball}} = -81\text{ms}$ ,  $M_{\text{control}} = -81\text{ms}$ ). We ran the same type of ANOVA to compare the LRP-R amplitudes between groups (three levels) as well and found no significant effects ( $F(2, 27) < 2$ ,  $p < 0.3$ ) there either. The trend of the means was in the expected direction,  $M_{\text{runner}} = -7.52\text{mV}$ ,  $M_{\text{basketball}} = -8.06\text{mV}$ ,  $M_{\text{control}} = -5.49\text{mV}$  (see Figure 3), with the basketball players having the largest amplitude, followed by the runners and lastly the controls. It may be possible that sport specific training may have an effect on the amplitude of the LRP-R since we did find differences between the groups but since the means were not significantly different this may have more to do with individual differences. Since no tests

reached significance these results indicate no significant effect of exercise on pre-motor cognitive processes.

*S-LRP*. It was worthwhile to look at congruency effects on the S-LRP and not the LRP-R because the LRP-R has to do with the motor response once a cortex is chosen. The S-LRP indicates the time from the onset of the stimulus until the lateralization; this is where effects of congruency would show up as opposed to in the motor reaction. We also ran a 3x2, group (three levels) by congruency (two levels), mixed ANOVA for the latency of the S-LRP. Here we excluded those subjects whose accuracy on the incongruent trials was less than 80% due to misunderstanding the directions as well as some subjects whose LRP waveforms were too noisy to identify an LRP peak. This left us with 6 subjects in each group. We found a significant main effect of congruency ( $F(1, 15) = 10.24, p < 0.007$ ) (see Figure 2). By looking at the means for the congruency conditions,  $M_{\text{congruent}} = 368\text{ms}$ ,  $M_{\text{incongruent}} = 432$ , (see Figure 3) we found that during the congruent trials the subjects' S-LRP peak was sooner than in the incongruent conditions as we predicted.

We ran the same 3x2 mixed ANOVA on the amplitude of the S-LRP. We found no significant effects indicating that there may be no effect of exercise on the amplitude but only on the latency of the S-LRP.

We then ran a bivariate correlation test comparing the VO2 max scores and the participants' S-LRP latency and amplitude for congruent and incongruent trials. The only correlation at significance was that between the VO2 max and the latency during congruent trials of the S-LRP ( $r = -0.45, p = 0.51$ ). The negative correlation indicates that as VO2 max rises (or as fitness increases) the latency of the S-LRP on congruent trials decreases.

### *Behavioral Analysis*

We ran a bivariate correlation test comparing the VO2 max values and the participants' accuracy and reaction times for both congruent and incongruent trials. Reaction times for both congruent and incongruent trials were marginally significant. Reaction time for congruent trials was inversely correlated with VO2 max values ( $r = -0.409, p < 0.080$ ) as were the incongruent trials ( $r = -0.396, p < 0.090$ ) as we predicted. A negative correlation was expected because we predicted that those who are more fit (with a higher VO2 max score) would respond faster, so as VO2 max increases reaction time decreases.

We then ran a mixed 3x2 group (three levels) by congruency (two levels: congruent and incongruent trials) ANOVA on the accuracy data, excluding those subjects whose accuracy on incongruent trials was below 80% and the basketball subject excluded from P300 analyses. Here we found a highly significant effect of congruency ( $F(1, 18) = 12.55, p < 0.003$ ) with the subjects being more accurate on congruent than incongruent trials, as predicted ( $M_{\text{congruent}} = 98.3\%$ ,  $M_{\text{incongruent}} = 93.5\%$ ). While there was no significant effect of group ( $F(2, 18) < 2, p < 0.3$ ) the means by group showed a trend in the opposite direction than predicted, with the controls being the most accurate ( $M = 97.6\%$ ) followed by the basketball players ( $M = 95.4\%$ ) and then the runners ( $M = 94.7\%$ ).

We ran another mixed 3x2 group by congruency ANOVA on the reaction time data. We again found a main effect of congruency ( $F(1, 18) = 40.96, p < 0.001$ ) and also a main effect of group ( $F(2, 18) = 3.58, p < 0.05$ ). As predicted the reaction time on congruent trials ( $M = 333$  ms) was faster than reaction time on incongruent trials ( $M = 423$  ms). The group means were not in the predicted direction, though. The runners had the fastest reaction average times for congruent and incongruent trials ( $M = 311$  ms) followed by the controls ( $M = 374$  ms) then the basketball players ( $M = 450$  ms). A Tukey's HSD post hoc analysis was done to determine that

only the runners and basketball players were significant different from one another in both the congruent ( $p = 0.059$ ) and incongruent ( $p 0.049$ ) trials. So while the runners and controls were faster than the basketball players only the runners were significantly faster at responding than the basketball players.

### Discussion

While there have been many findings of cognitive benefits from “exercise” we investigated whether there are benefits from sport specific exercise or whether simply being a fit individual was all it took for positive cognitive benefits (Polich & Lardon, 1997, Magnié et al., 2000, Hillman, Snook & Jerome, 2003). We predicted that our groups would differ significantly in their VO2 max scores with the runners having the lowest (indicating the highest level of fitness) followed by the basketball players and then the controls. We hypothesized that due to higher fitness levels the runners would have the fastest and largest P300 (shortest latencies and largest amplitudes) followed by the basketball players and then the controls. We also predicted that basketball players would have the shortest S-LRP latency due to their sport specific training as well as the fastest reaction times. We also predicted that the runners would follow them with the controls having the longest S-LRP latency assuming that the S-LRP is correlated with fitness levels as well.

#### *VO2 max*

Our VO2 max findings indicate that our groups were significantly different when it came to aerobic fitness levels, with the runners being the most fit, followed by the basketball players and then the controls. This indicates that breaking up athletes by group may yield results due to their aerobic fitness difference and that our controls were truly less fit in comparison to our athletes.

*P300*

We did find congruency effects, indicating that the Flanker's task was working, with the incongruent tasks being harder (shown by the slower reaction time) causing the subjects to take more time to evaluate the stimulus. This indicates that our method of eliciting and measuring the P300 worked, and that our findings could be related to previous studies (such as Polich & Lardon, 1997, Magnié et al., 2000, Hillman, Snook & Jerome, 2003). Our other P300 findings were difficult to interpret. The interaction effects of congruency by site indicate that one site (perhaps CZ) was conducting better and by doing so finding greater (and more accurate) values of amplitude and latency. It is also possible that CZ and PZ differed due to their difference in location as compared to the anterior cingulate cortex. The anterior cingulate cortex is found on the midline of the frontal lobe, closer to the CZ than the PZ electrode. The anterior cingulate cortex is thought to be involved in tasks where one must resolve conflicting information, such as in the incongruent trials of the Flankers task (van Veen, Cohen, Botvinick, Stenger and Carter, 2001; Botvinick, Cohen and Carter, 2004). The differences found at the PZ and CZ sites may be due to this difference in location and the use of the anterior cingulate cortex in incongruent trials which are thought to be linked to executive control functions rather than automatic response functions such as in a congruent trial. By breaking our subjects down by athletic sports group we found no significant overall difference between groups in latency or amplitude, indicating that the P300 is not affected by sport specific exercise. There was the marginal three-way effect found concerning the P300 latency. Post hoc analyses indicate that this was due to a difference between the congruent trials and the incongruent trials between the controls and the athletes. While the runners and basketball players differed only marginally between their congruent and incongruent trials the controls differed significantly. This means that the time difference between

their average latency for congruent trials and incongruent trials was greater than those of the athletes. This congruency difference indicates that the athletes were better at making the incongruent decisions, *as compared to their congruent trials*, than the controls were. This does not mean that the athletes were faster for congruent or incongruent trials, as the controls were actually fastest for these on average. It is rather the difference between the congruent and incongruent trials that was longer for the controls. It appears that the cognitive effects of exercise we found affect one's ability to evaluate stimuli with conflicting information more quickly than those who are not as fit.

By breaking the subjects into "athlete" and "non-athlete" groups we found more significant results, similar to those found by previous researchers (Polich & Lardon, 1997, Tomporowski & Ellis, 1986) which indicates exercise in general positively affects cognition as seen through effects on the P300. Our latency findings when we looked at the subjects separated into athlete or non-athlete groups were consistent with our earlier P300 findings. We found once again that the control subjects had a shorter latency than the athletes, indicating faster cognitive processing. We also found that the controls had a greater difference between their incongruent and congruent tasks, indicating that the effect of congruency is not just sport specific but linked to athletic exercise. This indicates that there may not be sport-specific training involved in increased cognitive abilities, rather simply the act of participating in sports, or aerobic exercise in general, that creates such differences.

### *LRP*

The response locked LRP data found no significant results, indicating that motor reaction reflected by the latency of the LRP-R is not influenced by exercise training but rather may be a fix reaction that cannot be changed. Since the LRP-R reflects the time it takes to execute the

action once the correct cortex has been selected it seems logical that this may be a fixed chain of events, differing only by individual difference. This is consistent with previous findings (Leuthold 2003; Osman, Moore & Ulrich, 1995). The only prior reports of possible effects on the latency of the LRP-R came from differences in personality (Rammsayer and Stahl, 2004) which were not evaluated in our study and are not relevant to the subjects' exercise habits. We did find the expected trend, though, when looking at the amplitudes by group. The basketball players did have the highest amplitude, followed by the runners and lastly the controls. This may indicate that sport specific training and exercise in general may affect the amplitude of the LRP-R. This does not indicate that exercise affects how quickly the LRP-R occurs. It does indicate that it may affect the amplitude which indicates the lateralization in our brains, that is, choosing which cortex to activate.

The only significant effects for the LRP were in the S-LRP data. The main effects of congruency simply show that our task (the Flankers task) was effective in that during the congruent trials subjects were able to process the stimuli faster so that they could activate the appropriate motor cortex faster than in the incongruent conditions. While there were no sport specific effects on the S-LRP our correlational data indicates that there is a connection between fitness levels and S-LRP latency. The more fit an individual the shorter their latency between the stimulus onset and the S-LRP (which indicates when the correct cortex is chosen to initiate movement).

These findings agree with previous research which indicates that the latency of the LRP-R is fixed, but can vary by individual while the S-LRP can be influenced by other aspects such as individual differences (Rammsayer & Stahl, 2004, Stahl & Rammsayer, 2004) in this case exercise. Our findings indicate that the more fit an individual the faster they are able to lateralize

movement. Since the basketball players were not significantly faster than the runners it seems that this is only affected by overall fitness and not sport specific training. The cognitive response, indicated by the S-LRP latency, where the motor cortices are deciding which cortex is necessary for the movement required, may be the part which is influenced by aerobic training, not the motor response, indicated by the LRP-R.

The amplitude of either LRP was not significantly different between the groups, like the Hung et al. (2004) study found. The difference in amplitude would have indicated a difference the lateralization process, more likely found in Hung et al.'s study (2004) due to their subjects, table tennis players, who would have to be able to decide in a split second which direction to go, whereas although basketball players likely have fine hand eye coordination there is a slower and less intense decision making process involving directionality or dexterity.

#### *Behavioral Data*

Our behavioral data indicates that fitness level tends to be inversely correlated with reaction time; as fitness increases speed of response increases. Combining this data with that of the LRP and P300 it seems that the difference has to do not with the motor preparation or action (S-LRP and LRP-R) but rather due to the cognitive evaluation of the stimuli. Based on our data it appears that the more fit one is the faster they are able to react to stimuli presented to them and that this difference is due to the cognitive rather than motor evaluation.

The reaction time post hoc analysis contains confusing information. While the runners, being the most fit, are the fastest at responding to the stimuli the basketball players are the slowest at responding, even though they are more fit than the controls. So is fitness really affecting reaction time? When looking at the difference between the incongruent and congruent trials for each group we find that the runners have the smallest congruency effect (75.73)

followed by the basketball players (95.66) and then the controls (99.64). This is consistent with our findings which suggest that exercise and fitness level affect one's ability to respond to the correct stimuli even when it is surrounded by conflicting information.

### *Overall Findings*

Unfortunately we found no significant effects of athletic group but we did find that by putting them into athlete and non-athlete groups the differences were more significant. Based on our data there seems to be a link between consistent long term exercise and effects on cognition, specifically a heightened ability to screen out extraneous information and focus on the important stimuli, indicated by the larger congruency effect in the P300 latency for control subjects over the runners and basketball players. Since we did find a significant difference between all three groups with their VO2 max scores it seems as though there was no significant difference in P300 latency and amplitude due to sport specificity. There was however a marginal trend in the latency of the incongruent and congruent trials. This may be seen as a difference in executive and automatic decision making. The congruent tasks were automatic decisions whereas the incongruent tasks were executive decisions, due to having to weed out the conflicting information. Based on our data exercise may help executive decision making by making it easier to filter out unnecessary information to be able to focus on the relevant information. Additionally the P300 and S-LRP data both point to this heightened ability to perform on the incongruent trials *as compared* to the group's congruent trials and that it was easier for athletes to make incongruent decisions as compared to their congruent trials.

### *Confounds in our Findings*

Our data did not corroborate previous research although we did find effects of exercise. This may be due in part to the small sample size. Once we accounted for noisy waves and correct

completion of the task we were often left with little more than half the original sample size. This loss of subjects may have played a role in another way. Our control subjects' VO<sub>2</sub> max scores varied greatly and it is possible that when we lost control subjects we lost those subjects who were truly controls in that they had very low VO<sub>2</sub> max scores and are not involved in any sporting events, including intramural.

We also had to contend with high impedance values. For the most part the impedances were below 30k $\Omega$ , but ranged between 0 k $\Omega$  and 430 k $\Omega$ . The mean was 25.91 k $\Omega$  and the median was 17 k $\Omega$ . The infrequent but high values were likely due to the caps being used so frequently and not being cleaned well. If this is the case then the electrodes would have conducted poorly, as we found. While this likely did not affect the values we found it may explain the PZ and CZ site differences. If one site was dirtier than another then they may not have recorded similar peaks, with the dirtier one having a possibly faulty reading. We tried to keep the impedance values below 50 k $\Omega$  so as to achieve the most accurate readings.

It is also important to note that our subjects were all healthy college males. Studies which have shown positive effects of exercise often use the elderly (Kramer et al., 1999, McAuley, Kramer & Colcombe, 2004). It is possible that the elderly have more to gain from exercise especially since most do not regularly get aerobic training. Young sedentary college men (working out less than 10 hours a week) may have a ceiling effect in their motor response and evaluation of stimuli as those who do not participate in sports are still probably more fit than a sedentary elderly person. This may have further complicated our results.

We did not get an extensive history for the participants and therefore were not able to assess possible long term affects of exercise. We only assessed current exercise habits and current activity in club, intramural and varsity sports. It seems possible from our data that long

term exercise is related to differences in cognition rather than short term exercise. It is a possible confound that we did not assess the participants' long term exercise background and were therefore unable to use this as another measure of fitness.

#### *Implications of our Findings and Possible Further Research*

Our findings confirm the positive affects of exercise on cognition. Additionally we have found a smaller congruency effect for athletes versus non-athletes. Our findings may also indicate that long term exercise (over the course of years) can, in young adults, affect their ability to focus on the relevant stimuli even when there is conflicting data surrounding it. This indicates that any type of long term exercise may affect cognitive evaluation of stimuli. There seems to be an effect of exercise on an individual's difference between executive and automatic decisions. In the incongruent trials there is an aspect of executive control, the need to block out extraneous information and focus on the relevant information, whereas in the congruent trials it is an automatic response. Our data indicates that for those who do not participate in regular exercise (like a sports team) have a harder time switching to use their executive control on the Flankers task. There were not, however, findings that implied that exercise affected the overall speed at which cognitive evaluation happened. One possibility to look at in further research would be to evaluate the latency and amplitude of the P300 in those who may participate in video or online games. Castel, Pratt and Drummond (2005) found that video game players were faster at detecting target stimuli than those subjects who did not play video games. If our control subjects play video games more often than our athletic subjects than this may account for their shorter latency times, although looking at the P300 in video game players has yet to happen.

Our findings indicate that there is an effect of exercise on cognition as well as motor reaction, but due to possible confounds within our control group it would be useful to look at

*long term* athletic activity and that effect on the P300 and LRP. Perhaps when breaking groups into long term versus short term athletic activity researchers may find that long term exercise yields faster and larger P300 waves, indicating that exercise does affect the P300 and that long term exercise can be beneficial to cognition. Based on our data we would expect that long term athletic activity is correlated with a larger congruency difference as well as slower reaction times, as we found similarly. Perhaps this might best be looked at in the elderly and comparing those who have exercised for years to those who just began and a group of sedentary controls as well. By seeing what effects exercise has over a lifetime may shed more light on what it is in the brain that exercise can affect.

While our findings did not support sport specific effects on cognition they did support previous research which suggests that exercise and physical fitness have positive effects on cognition (Polich & Lardon, 1997, Magnié et al., 2000, Hillman, Snook & Jerome, 2003). We found particularly that exercise may benefit one's ability to focus on relevant stimuli while ignoring irrelevant stimuli, cause a smaller congruency difference. We also found that those who are more physically fit react faster to a given stimuli and since we found no difference in our subjects' LRP-R this difference seems to be connected with increased cognitive arousal, particularly when laterizing (or determining which hand to use).

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## Appendix A

### Prescreening Questionnaire

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. If you complete the questionnaire below, which should take only about 5-10 minutes, we'll enter your name into a lottery drawing for a \$100 CASH PRIZE. As long as you complete this questionnaire, your name will be entered into the lottery, even if your responses on this questionnaire make you ineligible for participating in the full study later on.

If your responses indicate that you are eligible for the full study, we will contact you within a few weeks to tell you more about what the full study involves, and to see if you might be interested in participating. If you complete this questionnaire, it does not mean that you are committing yourself to completing the full study; you can make that decision later if it turns out that you've met the eligibility requirements. The ultimate purpose of the full study is to better understand individual differences in the brain's response to different types of visual images.

If you feel uncomfortable answering any question, please feel free to leave it blank. If you choose to leave a question blank, it will not affect your entry into the lottery for the cash prize. Remember that your responses to the questionnaire are confidential. Only Christine Cullen 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, Christine will remove all names from our data records, ensuring confidentiality and anonymity of your responses in the permanent record.

If you have any questions about the study, please contact Prof. Compton at 610-896-1309 or [rcompton@haverford.edu](mailto:rcompton@haverford.edu). If you have questions or concerns about your rights as a research participant, you may also contact Prof. Rob Scarrow (610-896-1218, [rscarrow@Haverford.edu](mailto:rscarrow@Haverford.edu)); Prof. Scarrow is chair of the Haverford College IRB, which oversees the protection of research participants.

Please check the box below to indicate that you have read the above instructions and that you voluntarily consent to have your responses below included in the dataset for this study.

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 a 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

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

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 sports 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 space 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](mailto:ccullen@haverford.edu)), Laura Chaddock ([lchaddoc@haverford.edu](mailto:lchaddoc@haverford.edu)) or LeeAnn Tanaka ([ltanaka@haverford.edu](mailto:ltanaka@haverford.edu)).

PLEASE NOTE: Your responses will not be submitted to our database until you click on the “SUBMIT” button below. By clicking on the SUBMIT button, you are granting your consent for your responses to be included in our database.

Figures and Tables

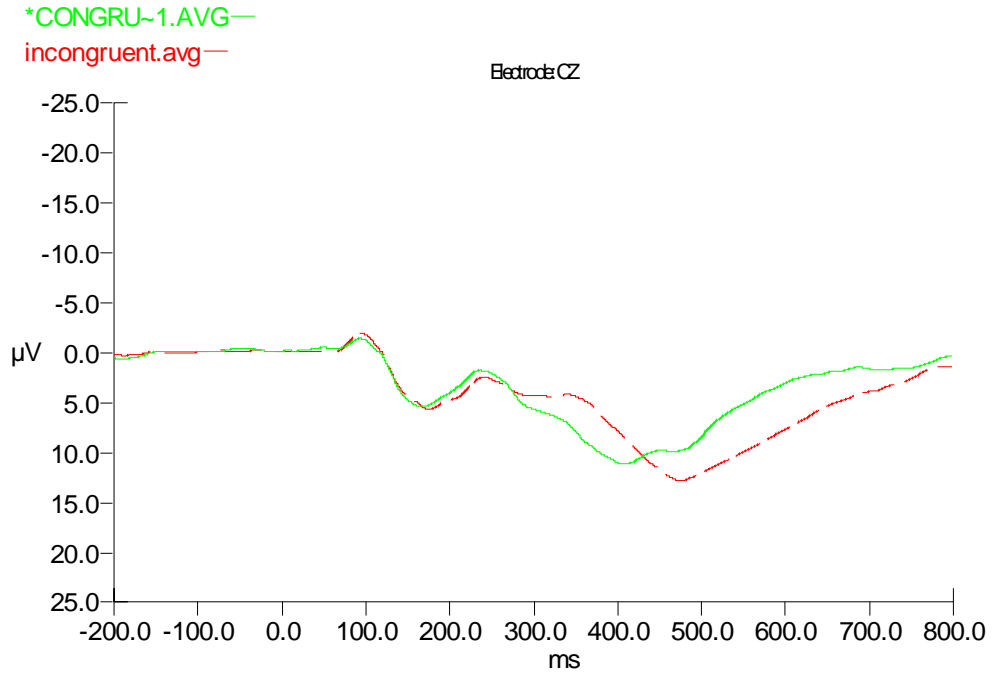


Figure 1. Grand average waveform depicting the P300 for congruent (solid line) and incongruent (dashed line) trials. Time 0 refers to the onset of the stimulus. The most positive peaks indicates the P300.

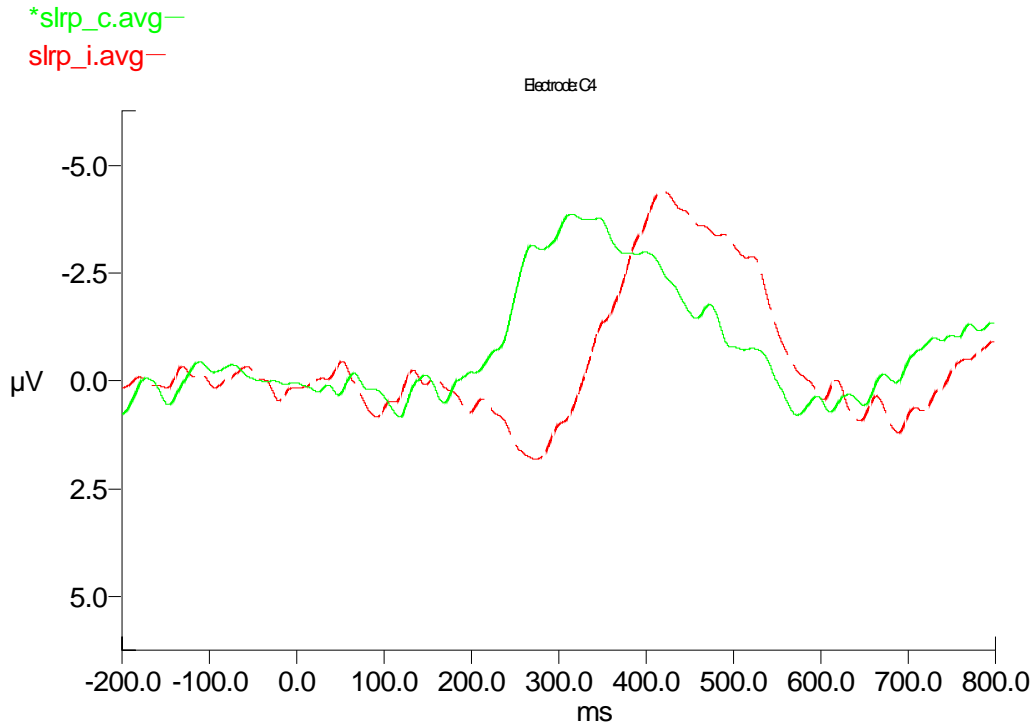


Figure 2. Grand average waveform depicting the S-LRP for the congruent (solid line) and incongruent (dashed line) trials. Time 0 refers to the onset of the stimulus. The most negative peaks indicate the S-LRP.

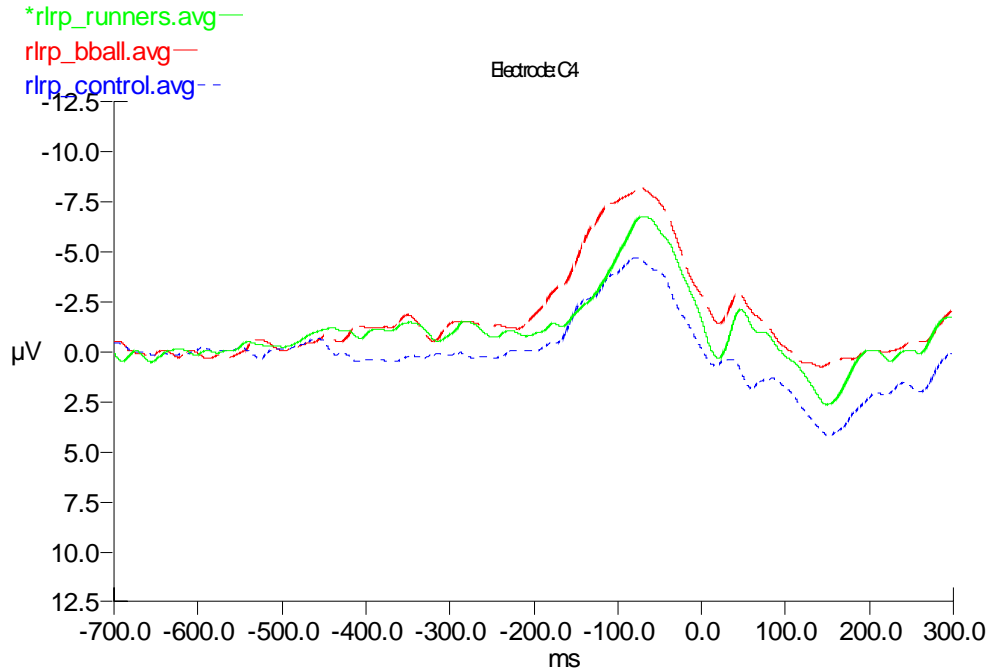


Figure 3. Grand average waveforms depicting the LRP-R for the runners (solid line), basketball players (dashed line) and control subjects (dotted line). Time 0 refers to the onset of the subject's response. The most negative peaks indicate the LRP-R.

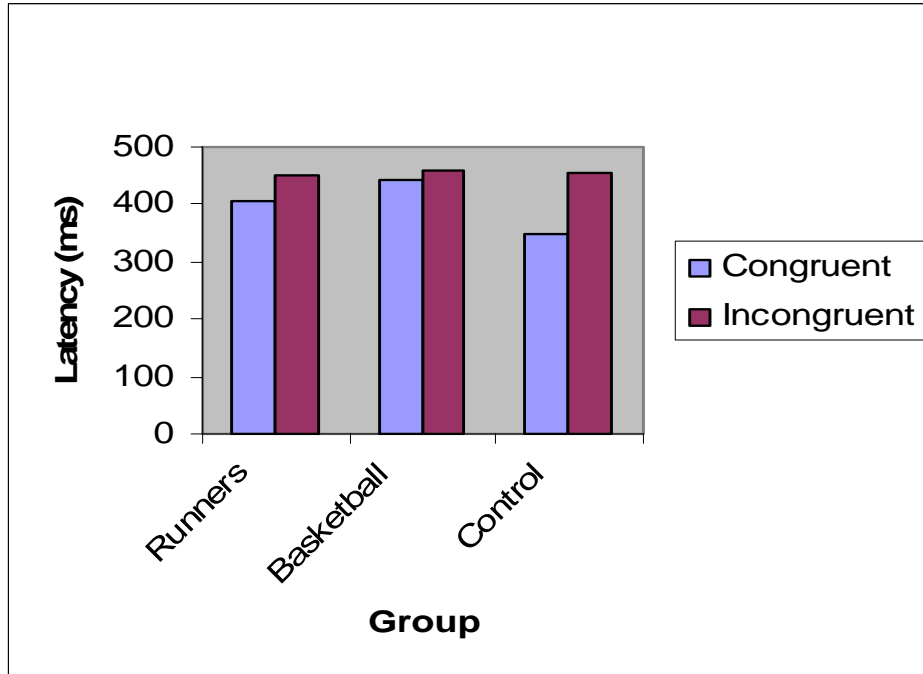


Figure 4. Average P300 Latency shown by Group by Congruency at Site CZ

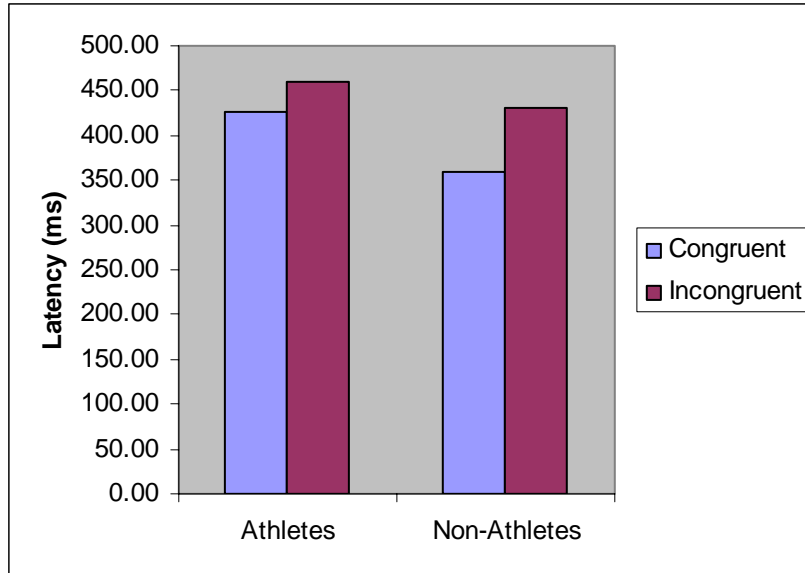


Figure 5. Average P300 Latency for Congruent and Incongruent Trials by Athlete Group.

Table 1.

*Average P300 Amplitudes by Congruency by Site*

Congruency	Site	Mean	Standard Error
Congruent	CZ	14.17 $\mu$ V	1.11
	PZ	14.41 $\mu$ V	0.92
Incongruent	CZ	14.79 $\mu$ V	1.44
	PZ	13.16 $\mu$ V	1.29

Table 2.

*Average P300 Latency and Amplitude by Group at CZ*

	Amplitude			Latency		
	Congruent	Incongruent	Difference	Congruent	Incongruent	Difference
Runner	15.73 $\mu$ V	16.12 $\mu$ V	0.39	404 ms	451 ms	47
Basketball	13.41 $\mu$ V	13.22 $\mu$ V	-0.19	443 ms	461 ms	18
Control	13.37 $\mu$ V	15.04 $\mu$ V	1.67	347 ms	457 ms	110