THE EFFECTS OF EXERCISE-INDUCED FATIGUE ON COGNITIVE FUNCTION

by

ROBERT DAVIS MOORE

(Under the Direction of Phillip Tomporowski)

ABSTRACT

The primary purpose of this thesis was to evaluate the effect of acute exercise-induced fatigue on cognitive function. A review of the literature on acute physical fatigue and cognitive function demonstrated that exercise induced fatigue may affect specific lower level sensory/perceptual processes. Following 60 minutes of cycle ergometry, participants who exercised reported significantly more physical fatigue and demonstrated significant decrements in performance on a complex visual-discrimination task compared to participants who rested, $p < .05$. Participants who exercised also demonstrated increased response times during a cognitive-vigilance test compared to participants who rested, $p < .05$. Neuroelectric measures were taken during cognitive testing and participants who exercised demonstrated lower P3 amplitudes for the simple version of the visual-discrimination test compared to participants who rested, $p < .05$. The current study adds to previous theory driven research by further demonstrating that lower level, automated cognitive processes appear to be influenced by exercise-induced fatigue while upper level executive processes remain unaffected. Further, this study is the first to our knowledge to evaluate the time course of physical fatigue effects. Participants evidenced decrements 75 minutes post physical activity intervention.

INDEX WORDS: Cognition, Cognitive, Fatigue, Neuroelectric, Perceptual, Sensory, Vigilance

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Chapter 1

INTRODUCTION

Rationale for the Study

Anecdotal evidence for the debilitating effects of acute physical fatigue on attention, cognition, and human performance is overwhelming. However, laboratory studies examining the relationship between acute physical fatigue and operational performance have found the phenomenon to be elusive.

Purpose of the Study

The purpose of the study was to test a theory-based model of fatigue, and to clarify the effects acute exercise-induced fatigue on cognitive function. The experiment directly addressed the short-term after effects of acute exercise by measuring cognitive performance for 75 minutes following the termination of a single 60-minute bout of cycle ergometry. Mental tests included sensory visual-discrimination tasks and a cognitive vigilance task.

Hypotheses

1) Compared to young adults who do not exercise, those who complete a 60-min bout of cycling at an intensity of 90% ventilatory threshold will detect fewer targets, make more errors of commission, and evidence reduced perceptual sensitivity during a sensory visual-discrimination task administered 15 minutes following the termination of the exercise protocol.

2) Compared to young adults who do not exercise, those who complete a 60-min bout of cycling at an intensity of 90% ventilatory threshold will detect fewer targets, make more

errors of commission, respond more slowly, and evidence reductions in target discriminability during a 40-min cognitive vigilance test administered 25 minutes following the termination of the exercise protocol.

3) Compared to young adults who do not exercise, those who complete a 60-min bout of cycling exercise at an intensity of 90% ventilatory threshold will detect fewer targets, make more errors of commission, and evidence reduced perceptual sensitivity during a visual sensory-discrimination task administered 75 minutes following the termination of the intervention. Further, the performance of participants in both treatment conditions will be lower during the second administration of the discrimination task than the first administration.

4) Performance on a complex version of the visual sensory-discrimination task administered 15 minutes and 75 minutes following exercise is predicted to be compromised more than for a simple version for those who exercise than those who do not exercise. The effect will be revealed in Group X Task Condition and a Group X Task Condition X Time interaction.

5) Measures of brain activation (event related potentials) taken during performance of the visual-discrimination tasks administered 15 and 75 minutes following exercise will differ between young adults who exercise and those who do not exercise. The magnitude of differences in amplitude and latency measures will be dependent on time and task difficulty. Individuals who exercise will demonstrate lower P3 amplitudes and longer latencies during the complex version of the visual discrimination task compared to those who do not exercise. This effect will reveal itself in a Group X Task Condition X Time interaction.

Definitions

Cognition- All processes by which sensory input is transformed, reduced, elaborated, stored, recovered and used.

Electroencephalography (EEG) is an electrophysiological method for analyzing brain activity.

Event related potentials (ERP) are particular EEG wave forms time locked to the occurrence of a stimulus.

Exercise- Exercise is a subclass of physical activity for carried out for the purpose of maintaining one or more aspects of physical fitness.

Fatigue- fatigue is defined as a reduction in the capacity to perform work.

Neurocognitive- the underlying cortical areas, pathways, and activity associated with particular cognitive function.

Physical activity- Physical activity is any bodily movement produced by skeletal muscle that results in energy expenditure.

Ventilatory threshold (VT)- Ventilatory threshold is the breakpoint at which pulmonary ventilation and carbon dioxide output begin to exponentially increase during an incremental exercise test.

VO_2 Peak- VO_2 Peak is an observed peak in oxygen consumption, while workload continues to increase. If a plateau is not observed during a bout of maximal effort, it is called Vo_2 Peak.

Chapter 2

THE EFFECTS EXERCISE-INDUCED FATIGUE ON COGNITIVE FUNCTION

REVIEW OF RELATED LITERATURE

Individuals who engage in heavy exertion or perform prolonged periods of physical activity often report that these activities reduce their ability to think, make logical judgments, and decisions. Human factors researchers have long been interested in explaining how physical fatigue affects human performance in applied settings. Laboratory-based research investigating the effects of acute physical activity on cognition has focused on central and peripheral fatigue fatigue (Meeusen, 2003). Central fatigue can be operationally defined as a reduction in the neural drive to muscles, which may lead to decrements in force production or tension development. Central fatigue occurs independently of changes in skeletal muscle contractility and peripherally fatiguing factors (Meeusen, 2003). Peripheral fatigue can be operationally defined as a decrease in the force generating capacity of a muscle or muscle group (Bigland-Ritchie & Woods 1984; Gandevia, 2001). Peripheral fatigue is hypothesized to involve factors that metabolically attenuate normal contractile processes, which leads to excitation-contraction coupling failure and results in a reduction of individual motor units' capacity to generate force (Selen, Beeks, van Diem, 2007). In order to maintain the same output, the central nervous system increases its drive to the muscles causing active motor units to fire more frequently and the recruitment of larger groups of motor units (Gates & Dingwell, 2008).

There is a well established and long standing theoretical interest in cognitive energetics (van der Molen, 1996). In the early 20th century, Yerkes and Dodson (1908) proposed the inverted-U hypothesis of arousal. Yerkes and Dodson stated that performance follows an inverted-U pattern, with optimal performance occurring under states of moderate arousal. Their research provided the basis for cognitive-energetic theories and models that have come to prominence over the past four decades (e.g., Kahneman, 1973; Humphreys & Revelle, 1984; Hockey, 1997). Contemporary cognitive energetic theories seek to explain performance in sport and human factors settings through hypothetical constructs such as arousal, activation, and mental effort. Kahneman's seminal research and theory (1973), focused on mental effort and the role it plays in the allocation of cognitive resources. Resources are defined as the amount of mental energy one has to allocate to any given task. An individual's allocation of resources is hypothesized to be determined by a policy structure that is influenced by four factors: enduring dispositions, which are linked to stimulus properties and responses triggered by novelty or complexity; momentary intentions, which refer to conscious decisions to pay attention to a stimulus; evaluation of task demands, which involves comparing current goal achieving capacity with available resources; and arousal, which is described in terms of physiological activation.

Hockey (1997) proposed a compensatory-control theory that builds upon previous energetic theories. Unique to his theory is an emphasis on the role of biological factors in explaining changes in human performance. Central to Hockey's energetic model are two feedback loops. Conscious information processes occur within an upper executive loop and the non-conscious information processes occurs within a lower-level loop.

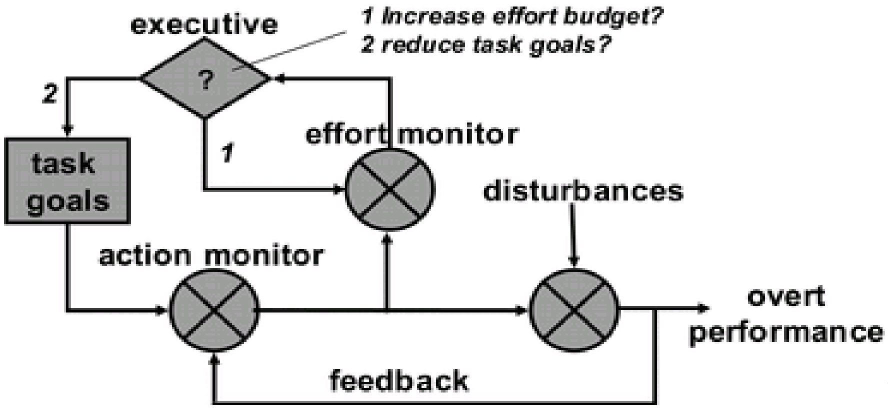

Figure 1. Hockey's Component Processing Model.

The executive loop, shown in (Figure 1), maintains task performance during conditions of stress. The action monitor working with a comparator (effort monitor), enables recognition and adjustment of discrepancies between current goal states and desired goal states (task goals). Non-conscious automatic processing is hypothesized to take place within the lower loop of the model. Processing in the lower loop regulates well learned actions, which can be modified in response to minor variations in task demands. When discrepancies caused by variations in task demands exceed a threshold, the upper executive loop detects the occurrence and allocates greater cognitive resources to the task. In summary, Hockey (1997) predicts that the maintenance of human performance is an active process controlled by the individual and necessitates the management of cognitive resources by mobilizing mental effort. Hockey hypothesizes that task behavior can be maintained in accordance with current goals relative to available energetic resources. Hockey's theory accounts for control and maintenance of information processing during conditions of stress.

Extended bouts of exercise have been used in several experiments to model the effects of stress and fatigue on human performance and cognition. Extended bouts of exercise can be defined as bouts in which participants exercise aerobically and below their ventilatory threshold for an extended period of time, (i.e., an hour or more). Cian, Koulmannn, Barraud, Raphel, Jimenez, and Melin (2000) employed a protocol in which young men ran on a treadmill at an intensity that approximated 60% of their maximum output for 2 hours. Participants were randomly assigned into one of two groups and began the session euhydrated but were not allowed to hydrate during exercise. Participants completed a battery of cognitive tests prior to and following exercise at multiple time points. The cognitive test battery was composed of choice reaction-time, tracking, perceptual-discrimination, short-term memory, and long-term memory tests. Fifteen minutes after exercise both groups were administered the cognitive test battery. Participants demonstrated impairments for tracking, perceptual-discrimination, and short-term memory relative to baseline. No effects were observed for choice reaction-time or long-term memory. Individuals in one group were then rehydrated and 30 minutes later both groups were administered the same cognitive test battery. Participants in both groups demonstrated impairments in choice reaction-time and maintained impairments for short-term memory. No effects were observed on the other tests. In a systematic replication experiment by Cian, Barraud, Melin, and Raphel, (2001) young men ran for 2 hours at an intensity that approximated 65% of their maximum output. As in their earlier experiment, participants were not allowed to hydrate during exercise. The cognitive test battery employed in their earlier experiment was administered prior to and following exercise at multiple time points. Fifteen minutes after exercise participants in both groups evidenced impairment for the perceptual-discrimination and short-term memory test following exercise. No effects were observed for tracking or choice reaction-time or long-term memory. Individuals in one group were then rehydrated and both groups were administered the cognitive test battery two hours later.

Following hydration, participants in both groups demonstrated impairment during the perceptual-discrimination test, and improved short-term memory. No effects were observed for the other tests for either group.

The experiments conducted by Cian and her colleagues (2000; 2001) evaluated the combined effects of both dehydration and extended bouts of aerobic activity, confounding the relationship of exercise-induced fatigue and cognitive function. However, there are experiments that have isolated the effects of extended bouts of aerobic activity on cognitive function. Tomporowski, Beasman, Ganio, and Cureton (2007) evaluated 11 highly trained young men's cognitive performance following two hours of cycle ergometry at a rate and resistance that approximated 60% VO_{2max} and a 15-minute performance ride at a rate and resistance that approximated 90% VO_{2max} . Participants completed two experimental sessions. In one session, participants cycled for two hours without fluid replacement, and in the other session, participants cycled for two hours with fluid replacement. Cognitive tests that measured executive processing, (a categorical switching task) and short-term memory (Brown-Peterson test) were administered prior to and immediately following exercise. Following exercise, dehydration that reduced body weight by 2% led to an increase in participants' frequency in errors of commission (i.e., false alarms) during the executive set-shifting task performance, whereas, no changes in set-shifting performance was observed when participants were hydrated. Short-term memory performance improved significantly for participants during both hydration and dehydration conditions.

Hogervost, Riedel, Jeukendrup, and Jolles (1996) had 15 highly trained athletes cycle on an ergometer for 60 minutes. Participants cycled at a rate and resistance that approximated 75% of their maximum power output. Prior to and immediately following exercise, participants completed a cognitive battery of tests that included the Stroop task, a simple-reaction test, a choice-reaction test, and finger-tapping test. Improvements in executive function (Stroop Task performance), and simple-reaction-time were observed following exercise. Choice reaction-time and finger tapping tests were not affected by the intervention.

Grego et al., (2004) evaluated the effects of an ergometry cycling bout on 12 trained young men's neurocognitive function. Participants cycled for three hours at a rate and resistance that approximated 66% of their maximum output. Neuroelectric measures were taken during an auditory detection task administered at several time points during and following the exercise bout. During exercise significant increases in P3 latency were observed at 108 and 144 minutes of cycling. Immediately following exercise termination, participants exhibited increased P3 latency compared to pre-exercise P3 measures. Further, P3 latency measures were still reduced 15 minutes after exercise cessation. In sum, relatively few studies examining physical fatigue have evaluated the effects of long-duration aerobic exercise on cognitive function. The evidence that is available suggests that exercise induced fatigue on cognitive function may be selective with the greatest impact on simple tasks carrying low attention demands. Lacking, however, are experiments designed to assess the time course of the short-term after effects of an extended bout of exercise on tasks that differ in attentional resource demands. Based on Hockey's (1997) compensatory-control theory, exercise-induced fatigue is predicted to negatively impact performance during a complex but not during a simple perceptual-discrimination test and performance during a vigilance test that requires sustained attention.

Chapter 3

METHODS

Participants

Participants: Thirty subjects were recruited through classes in the Department of Kinesiology and via posted fliers. Inclusion criteria for participating included being between 18 to 28 years of age, a history of engaging in regular physical activity, no contraindications to strenuous exercise as described by a medical history questionnaire, right handed, and normal vision of at least 20/30 or corrected to normal vision. Additional exclusion criteria included taking of certain medications, such as for allergies or Attention Deficit Disorder.

Instrumentation

Participants were provided instructions and training to perform two computer-generated cognitive tests: a visual-discrimination test and a cognitive-vigilance test. The visual-discrimination test was a systematic replication of one developed by Pontifex, Polich and Hillman, (2009). The protocol consisted of a simple two-stimulus test and a complex three-stimulus discrimination test. In the simple form, circles of two different diameters were presented successively at the center of a computer screen. Forty target circles were presented that had a diameter of 5.5 cm and occurred on 20% of trials. Non-target circles had a diameter of 3 cm and occurred on 80% of trials. In the complex form, three different stimuli were presented. Twenty-five target circles were presents that had a 5.5 cm diameter and occurred at 12.5% of trials. Non-target circles had a 5.0 cm circle and occurred on 75% of trials, and a distracter square (2.0 cm) occurred on 12.5 % of trials. For both versions, stimuli were presented for 300 milliseconds, with an inter-stimulus interval of 700 milliseconds. Each version of the test consists of 200 trials and required approximately 4 minutes to complete. During the tests, participants were seated in a chair in front of a computer. The tests were developed on Super lab 4.0 software, (Cedrus Corporation, San Pedro, CA). Responses to target stimuli were made via a commercial response pad (Cedrus Corporation, San Pedro, CA) designed to record responses within 1 msec.

The cognitive-vigilance test was based on one described by Bakan (1955). On each trial, five digits were presented horizontally at the center of a monitor for 300 milliseconds followed by a 700 millisecond inter-stimulus interval. The numbers were 1.5 cm in height and separated by .5 cm. Subjects were instructed to ignore the two numbers on either side of the target number, which served as flankers or distracting stimuli. Participants were instructed to press a response key when three consecutive middle numbers that were odd and non repetitive were presented. The test consisted of four, 10-minute blocks. For each block there were 30 targets and 570 non-targets; the probability of target presentation was equal across each 10-min block.

Participants were trained to respond to two rating scales: Perceived Exertion and the Mental and Physical State Energy and Fatigue Scale. The 6-20 Perceived Exertion Scale was developed by Gunnar Borg 6-20 (1970). The scale is a standardized rating instrument that allows subjects to rate how hard they feel they are exercising. A numerical rating ranging from 6 (very, very light effort) to 20 (maximal effort) corresponds to the perceived intensity of the exercise. The Mental and Physical State and Trait Energy and Fatigue Scale (O'Connor, 2006), measures acute and chronic feelings of mental and physical energy and fatigue. The scales consist of 12 items that measures four energy and fatigue mood states: Physical Energy State, Physical Fatigue State, Mental Energy State, and Mental Fatigue State. Each trait construct is inferred from three items. The questions inquire about the frequency of usual feelings. The response categories are “never”, “a little bit of the time”, “sometimes”, “most of the time”, and “always”. Scores for the four subscales were computed by adding the raw scores from the three items that make up each sub-scale. Each state item inquires about the intensity of current feelings. The anchoring phrases of the 10-cm visual analog scale items were constructed to facilitate measuring the intensity of feelings ranging from the absence of a particular feeling to the strongest feelings that an individual has ever experienced. Raw scores for all 12 items were determined by using a ruler to measure the distance in millimeters from the left edge of each horizontal line to the vertical mark made on the line by the respondent. These scores can range from 0 to 100. Scores for the four subscales were computed by adding the raw scores from the three items that make up each sub-scale. Electroencephalography: Electroencephalographic (EEG) activity was recorded from 9 electrode sites, (Fz, Cz, Pz, F3, C3, P3, F4, C4, P4); according to the International 10-20 system (Jasper, 1958). All neuroelectric data was acquired, reduced, and averaged using BioPak 4.1 bioinformation systems. The Pz site served as the ground electrode and was reference to linked earlobe electrodes. Electrodes were also placed above and below the right eye, and at the canthus of either eye, to measure electro-occulogram (EOG) activity. Continuous data were digitized using a 1000 Hz sampling rate and amplified 500 times with a digital converter utilizing a 70 Hz filter. A notch filter of 60Hz and a low pass filter of 30 Hz were utilized. The rejection criterion was trials with artifact or response error of +/- 75 mV. Epochs were from -100ms stimulus onset to 1000 ms post stimulus onset. Trials were baseline corrected using the 100ms pre-stimulus period. The P3 waveform was defined as the largest positive going waveform from 300-800 ms post stimulus onset; with amplitude being the difference between the mean baseline amplitude and the maximum positive peak from 300-800ms, and latency corresponding to this maximum peak.

Testing Procedure

Participants attended two laboratory sessions: an orientation session and a test session. The orientation session consisted of four phases.

1) Each subject began the first session by reading the informed consent and completing a battery of questionnaires. Questionnaires gathered information about the participant's medical history, physical activity, and mental activity, feelings of energy, fatigue, sleep, diet, medication and supplement intake. (See appendix A). Upon completion, the investigator or research assistant answered questions, reviewed forms for screening criteria, and obtained written informed consent.

2) During the second phase, the researcher described the visual-discrimination test (i.e., the odd-ball test) and the cognitive-vigilance test and participants practiced each test. Participants were instructed to perform the visual-discrimination test and were familiarized to the stimuli. Participants then practiced 20 trials of the simple form of the test with an elongated stimulus presentation time (600 ms) and inter-stimulus interval (1400 ms). Participants then completed 100 practice trials with a stimulus presentation duration (300 ms) and inter-stimulus interval (700 ms), which was identical to conditions experienced during the test session. Participants were then trained to perform the complex version of the visual-discrimination test. If a participant correctly detected 80% or more of the targets, then he/she proceeded to practice the cognitive-vigilance test. If the participant did not meet the criterion, training was repeated until the criterion was met. Participants received instructions for the cognitive-vigilance test and were familiarized with the stimuli. Participants completed 20 trials with only one number being presented at a time. Participants then completed 20 trials with five numbers being presented at once with an elongated stimulus presentation time (600 ms), and an inter-stimulus interval (1400

ms). Participants then completed a longer practice block (600 trials), with a stimulus presentation duration (300 ms), and an inter-stimulus interval (700 ms) that were identical to the test session.

3) The third phase included a description and explanation of the rating scales participants used to judge ratings of perceived exertion, fatigue, and energy. The participant completed two fatigue and energy questionnaires.

4) In the last phase, participants assigned to the exercise group completed a graded exercise test, which provided a measure of peak oxygen uptake. The participants exercised on a cycle ergometer in a comfortable environment (approximate air temperature was 70 degrees F). The cycling portion began with two minutes of respiratory sampling, followed by a five minute warm up phase at 25 watts. Then the exercise phase began, and participants cycled at 50 watts and increased in intensity by 15 Watts every minute. The test terminated when the participant voluntarily stopped because he/she could not maintain the current workload. The participants engaged in a “cool down” exercise consisting of pedaling without resistance. Session 1 was completed in less than 90 minutes and concluded by confirming the participant’s next test session which began at the same time the next day. They were instructed to drink liberally the day before and to drink an 8-oz glass of water an hour before the session. Also, participants were instructed to abstain from eating a large meal two hours prior to cycling. Participants were asked not to alter their routine intake of stimulant beverages. They also were instructed not to engage in exhausting exercise the day of testing.

The experimental test session consisted of two phases. In the first phase, each participant completed a battery of 24-hour History questionnaires. The questionnaires asked participants about diet, sleep, physical activity, medication and supplements intake. Participants assigned to the exercise condition performed a 60-minute bout of cycle ergometry. The exercise protocol involved: (1) providing an overview of the cycling protocol and applying a heart rate monitor, (2) mounting and adjusting ergometer seating, (3) sitting on the cycle ergometer for two minutes without exercising, (4) a five minute warm-up period of cycling at 30% of the participant's VO_2 peak, and (5) a 55-minute exercise bout at 90% of the participant's ventilatory threshold . Participants rated their perceived exertion using Borg's 6-20 RPE scale upon mounting the bike and every 10 minutes during exercise. Participants also reported their levels of fatigue using a State/Trait Energy and Fatigue scale; once prior to exercise and immediately after the exercise period.

After exercise, the participant dismounted from the ergometer and was prepared for EEG testing, which took approximately 15 minutes. Electrode cap and electro-oculogram (EOG) preparation was done in accordance with standard practice using the international 10-20 electrode positioning system. Participants were prepared for EOG placement; the researcher sterilized the canthus, just horizontal to each eye, above the eyebrow and on the cheekbone proximal to the right eye. Gold cup electrodes were then placed at each site. Ear lobes were then prepared by the same process except the ears were gently abraded and then re-sterilized. Clasp-cup electrodes were placed on each ear lobe. The researcher inserted a blunt tip needle into each electrode and gently abraded and filled the electrode. An electrode cap was then placed on the participant and harnessed to an elastic band placed around the chest of the participant to prevent extraneous head movements. Similarly, a researcher gently abraded and filled 9 electrodes on the cap, (sites P3, P4, Pz, C3, C4, Cz, F3, F4, Fz, international 10-20 system). Impedance was checked before and after cognitive testing with all sites being maintained below 5 kΩ.

Once the participant was prepared for EEG recording, he/she was led to a testing room and sat in front of a computer monitor. The electrode cap was connected to a set of amplifiers.

The experimenter left the room and observed the participant’s test behavior via a TV monitor located in an adjacent room. The monitor did not record and was used for the sole purpose of identifying behaviors that interfere with EEG recording. The participant’s EEG waveform data was gathered while he/she performed the two visual-discrimination tests and the cognitive vigilance test and stored via commercial software (Biopac 4.1). Participants were asked to rate their levels of mental and physical energy five times during testing: pre-intervention, post-intervention, following the first administration of the visual-discrimination test, following the cognitive-vigilance test, and following the second administration of the visual-discrimination test. Following the final visual-discrimination test, EEG cables were disconnected and the participant was led to the laboratory area where the EEG cap and EOG electrodes were removed and the participant’s skin was cleaned. At the end of testing, a research assistant debriefed participants, described the intent of the study, and provided answers to any questions posed by participants

Participants assigned to the rest condition performed the same tests as described above with the exception that he/she lay down on bed located in the laboratory. Ratings of perceived exertion were taken upon lying down and every 10 minutes during rest. Participants reported their levels of fatigue using a State/Trait Energy and Fatigue scale; once prior to rest, immediately following rest, following the first administration of the visual-discrimination test, after completion of the cognitive-vigilance test and after completion of the last visual-discrimination test. At the end of testing, a research assistant debriefed participants, described the intent of the study, and provided answers to any questions posed by participants. The experimental session lasted approximately 3.5 hours.

Research Design

A between-group experimental design was employed. In each condition, 15 participants performed an 8-minute baseline visual-discrimination test before rest or exercise. After experimental treatment, participants performed in succession, an 8-min visual-discrimination test, a 40-min cognitive-vigilance test, and a second 8-min visual-discrimination test. In one condition, the mental tests were performed following a 60-min bout of cycling at a resistance that elicited a workload equal to 90% ventilatory threshold. In the other condition, the tests were performed following a 60-minute period of quite rest. Throughout exercise/rest testing several physiological and psychological measures were taken.

Data Analysis

Behavioral data obtained from each visual-discrimination test included the number correct target detections (Hits), number of errors of commission (False Alarms), and a non-parametric signal-detection index of sensitivity, P(A), that was based on the proportion of hits and false alarms (Green & Swets, 1974). The sensitivity index, P(A), represents the percentage of area under the ROC curve that corresponds to one hit and false alarm pair for an individual (Grier, 1971). The method used to calculate P(A) is described by Formula 1:

$$P(A) = \frac{.5 + (Y-X)(1.0+Y-X)}{4Y(1.0-X)}$$

where Y = the probability of a hit and X = the probability of a false alarm

Neuroelectric data were extracted from individual participant's EEG recordings. Recordings were obtained for the simple and complex conditions of the visual-discrimination task. Electro-occulogram artifacts were reduced from the raw data using Biopac (4.1) Independent Component Analysis (ICA). Independent component analysis enables the identification and separation of eye movements from the EEG signal by separating individual components by kurtosis of their amplitude distribution over time, which allows for the identification of periodical signals, regularly occurring signals and irregularly occurring signals. The process isolates pure eye activity in the EEG recording, and allows extraction of EOG signals while minimizing removal from the EEG recordings (Vigario, 1997). Trials in which incorrect responses were made were removed from the data set. Data obtained from correct responses were analyzed for the presence of excessive artifacts. Trials with an artifact level greater than +/- 75mV during the period between 100 ms prior to stimulus onset to 1000 ms post stimulus onset were rejected. Data obtained during the epoch were then averaged. Following averaging, trials were baseline corrected using the 100ms pre-stimulus period. The mean amplitude measured during 100 ms prior to stimulus onset period was then deducted from the individual's averaged waveform. The P3 waveform was defined as the largest positive going waveform between 300 and 800 ms post stimulus onset. Amplitude was measured as the difference between the mean baseline amplitude and the maximum positive peak from 300-800ms. Latency corresponded to the interval between stimulus onset and the maximum peak. Grand averages for each group and condition were constructed by summing data points across all participants and then dividing by the total number of participants.

Mixed-model ANOVAs were conducted on measures obtained from the visual discrimination tests, the cognitive vigilance test, and electroencephalography. The statistical model used to assess the visual-discrimination tests data was a 2 (Group: Exercise, Rest) X 2 (Test: Simple, Complex) X 2 (Time: First, Second administration) ANOVA, with group assignment being the between-subject factor and test and time being within-subject factors. A priori planned contrasts (Helmert) compared participants' baseline and post-intervention performance. Measures obtained from the cognitive vigilance test were assessed in a 2 (Group: Exercise, Rest) X 4 (Time: 4 Blocks) ANOVA, with group being the between subjects factor and time being a within-subjects factor. A summed average P3 latency and amplitude was computed for the three midline sites Pz, Cz, and Fz, and the site with the greatest amplitude (Pz) was identified. Neuroelectric measures were assessed in a 2 (Group: Exercise, Rest) X 2 (Time: 2 administrations) ANOVA, with group being the between factor and time being the within factor. All statistical tests employed a $p<.05$ criterion for statistical significance. Additional planned comparisons were used to evaluate participants' baseline performance with their combined performance following the intervention. Intraclass correlation coefficients (ICC) of performances observed during visual-discrimination tests and cognitive-vigilance test were assessed for individuals assigned to the rest condition. The reliability indices were assessed and reported according to the procedures and recommendations provided by McGraw and Wong (1996). Intraclass coefficients of correlation were calculated with a two-way mixed effects model, where people effects were random and measure effects (block of trials) were fixed.

Chapter 4

RESULTS

Visual-discrimination test performance: Planned contrasts were employed to compare participants' baseline discrimination performance to their performance on tests administered 15 minutes and 75 following the termination of the intervention.

Signal-detection analysis: A series of planned contrasts were employed to compare participants' baseline signal detection performance during the visual-discrimination tests to their performance during tests when administered 15 minutes and 75 minutes following the termination of the intervention (See Figure 2). The initial analysis evaluated participants' performance on both simple and complex versions of the visual-discrimination test. The analysis of P(A) scores revealed that participants' performance on the simple and complex tests differed significantly, $F(1,28) = 147.93$, $p < 0.001$, $\acute{\eta}_p^2 = 0.84$; performance was significantly lower during the complex version of the test. A planned contrast that compared participant's baseline test performance with their combined performance on the second and third administration of the tests revealed a three-way interaction, $F(1,28) = 4.56$, $p = 0.04$, $\acute{\eta}_p^2 = 0.14$, suggesting that performance depended on the type of intervention (exercise or rest) and test type (simple or complex) and time. A subsequent analysis of participants' performance on the simple version of the discrimination test did not detect differences between the performance of those assigned to exercise or rest condition, $F(2,56) = .22$, $p = 0.64$, $\acute{\eta}_p^2 = .008$; the planned contrast did not reveal any performance differences due to group membership or time of test, $F(1,28) = .78$, $p = .60$, $\acute{\eta}_p^2 = 0.10$. ICC = 0.40 for the rest group. An analysis of participants' performance on the complex version of the test yielded a significant interaction between group membership and performance on the three tests, *F*(1,28) = 4.68, p = 0.04, $ή_p^2$ = 0.11. The planned contrast between participants' baseline performance and their combined performance on the second and third administration of the test was significant, *F*(2,56) = 4.69, p = 0.039, $ή_p^2$ = 0.143. ICC = 0.91 for the rest group. Following exercise, participants evidenced a decline in perceptual sensitivity that was not observed following rest. Exerciser's performance during the second and third administration of the test did not differ.

Target detection analysis (Hit): The analysis revealed that participants' performance on the simple and complex tests differed significantly, *F*(1,28) = 138.10, p =.001, $ή_p^2$ = .831, (See Figure 3). Participants detected significantly fewer target on the complex version of the test. The planned contrast that compared participants' baseline test performance with their combined performance on the second and third administration of the tests revealed an interaction between time and test, *F*(2,56) = 8.10, p =.008, $ή_p^2$ =.224, suggesting that performance depended on time and test type. Subsequent analysis of participants' performance on the simple version of the discrimination test did not detect differences between the performance of those assigned to the exercise or rest condition, *F*(1,28) = .02, p = 0.88, $ή_p^2$ = .001. Planned contrasts did not reveal any performance differences due to group membership or time of test, *F*(2,56) = .07, p = .079, $ή_p^2$ = 0.003. ICC = 0.40 for the rest group. An analysis of participants' hits on the complex version of the discrimination test did not detect differences between performance of those assigned to exercise or rest, *F*(1,28) = .04, p =.831, $ή_p^2$ = .002. The planned contrast between participants' baseline correct detections and their combined correct detections on the second and third administration during the complex version of the test reveal an effect for time, *F*(2,56) = 8.93, p = .006, $ή_p^2$ = 0.242. Both groups' participants evidenced a decline in hits following intervention. Neither groups' hits differed between the second and third administration of the complex version of the test, $F(2,56) = 2.48$, p = .763, $\acute{\eta}_p^2$ = .003. ICC = 0.91 for the rest group.

False Alarm analysis (FA): The initial analysis evaluated participants' FAs during simple and complex versions of the visual-discrimination test (See Figure 4). The analysis revealed a significant difference between participants' FAs on the simple and complex tests, $F(1,28) = 9.31$, p = .005, $\acute{\eta}_p^2$ = .25. Participants committed significantly more FAs on the complex version of the test. The planned contrast that compared participant's baseline FAs with their combined performance during the second and third administration of the visual-discrimination test did not reveal an interaction between group membership and time of test, $F(2,56) = .04$, p = .842 , $\acute{\eta}_p^2$ = . 001. A subsequent analysis of participants' FAs on the simple version discrimination test did not reveal a difference in group performance, $F(1,28) = .01$, p = 0. 933, $\acute{\eta}_p^2$ = .001. The planned contrast did not reveal any differences in participants FA's due to group membership or time of test, $F(2,56) = .07$, p = .079, $\acute{\eta}_p^2$ = 0.003. ICC = 0.93 for the rest group. An analysis of participants' FA's on the complex version of the discrimination test did not detect differences in group performance, $F(1,28) = 1.83$, p =.186, $\acute{\eta}_p^2$ = .062. The planned contrast between participants' baseline FA's and their combined FA's on the second and third administration during the complex version of the test did not reveal any differences, $F(2,56) = .03$, p = .861, $\acute{\eta}_p^2$ = 0.001. Neither groups' FA's differed during the second and third administration of the complex version of the test, $F(1,28) = 2.98$, p = .095, $\acute{\eta}_p^2$ = .001. ICC = 0.91 for the rest group.

Cognitive-vigilance test: Detection performance of the participants assigned to the exercise and rest condition was assess during four successive 10-min time periods.

Signal Detection analysis: Analyses of measures of perceptual sensitivity P(A) shown in (Figure 5), did not reveal any differences between the performance of individuals who exercised and those who rested, *F*(1,28) = .01, p =.933., $\acute{\eta}_p^2$ = .001. There was no change in P(A) scores across the four 10-min blocks of testing, *F*(3, 84) = 1.89, p = .136, $\acute{\eta}_p^2$ = .015. ICC = 0.85 for the rest group.

Target detection analysis (Hit): Participants' target-detection performance as seen in (Figure 6), did not differ across four 10-minute time blocks, *F*(3,84) = 2.16, p = 0.09, $\acute{\eta}_p^2$ = 0.072, nor did performance differ as a function of group membership, *F*(1,28) = .01, p = 0.96, $\acute{\eta}_p^2$ = 0.001, or its interaction, *F*(3,84) = 0.40, p = 0.75, $\acute{\eta}_p^2$ = 0.014. ICC = 0.85 for the rest group.

False Alarm Analysis (FA): Shown in (Figure 7), the proportion of participants' errors of commission was low, with mean FAs ranging between 0.7 to 1.5 percent. The number of participants' FAs decreased significantly across the four 10-min time blocks, *F*(3, 84) = 4.28, p = .006, $\acute{\eta}_p^2$ = 0.137, and in a linear fashion, *F*(1, 28) = 6.85, p = 0.14, $\acute{\eta}_p^2$ = .196, for both groups. ICC = .60 for the rest group.

Response Time analysis (RT): The mean intervals between the onset of target stimuli and participants' depression of the response key for each of four 10-min test blocks as shown in (Figure 8). Participants' RT performance across the four time blocks did not differ as a function of time, *F*(3,84) = 2.21, p = 0.09, $\acute{\eta}_p^2$ = .073, nor did it depend on group membership, *F*(1, 28) = .12, p = 0.947, $\acute{\eta}_p^2$ = .004. Participants who exercised exhibited significantly longer RTs throughout the vigilance test than did individuals assigned to the rest condition, *F*(1, 28) = 5.17, p = 0.03, $\acute{\eta}_p^2$ = 0.156. ICC = 0.91 for the rest group.

Neuroelectric Data: A set criteria for data analysis was employed based on the recommendations of Cohen and Best (1997). Individual participants' data required a minimum of 20 trials that corresponded to a correct response and that were below artifact rejection criteria to be analyzed.

Simple visual-discrimination test: Of the 15 participants in each group, 14 participants in the rest group and 9 participants in the exercise group had data sufficient for averaging during the second and third administration of the simple version of the visual-discrimination test. Statistical analysis of P3 amplitudes for the simple visual-discrimination condition shown in (Figure 9) revealed a group difference, *F*(1,21)= 5.26, p= .032, $\acute{\eta}_p^2$= .200, for both administrations of the visual-discrimination test. P3 amplitudes were significantly lower for those who exercised compared to those who rested. No differences were observed for time, *F*(1,21)= .01, p=.902, $\acute{\eta}_p^2$= .001. ICC = 0.92 for the rest group. Analysis of P3 amplitude did not reveal any interaction between group membership and time, F(1,21)= .07, p= .788, $\acute{\eta}_p^2$= .001.

Analysis of the P3 latency as seen in (Figure 10) did not reveal any group differences, *F*(1,21)= .26, p=.616, $\acute{\eta}_p^2$ = .012. Further, no differences for time, *F*(1,21)= 1.06, p= .354, $\acute{\eta}_p^2$ = .041, or the interaction of time and group membership were observed for simple visual-discrimination latency, *F*(1,21)= 1.06, p= .313, $\acute{\eta}_p^2$ = .048. ICC = 0.87 for the rest group.

Complex visual-discrimination test: Based on the established rejection criteria, none of the electrophysiological data obtained during the complex version of the visual-discrimination test were acceptable for analysis.

Subjective energy and fatigue data: Measures of physical energy and fatigue and mental energy and fatigue were recorded at five time points during the experimental session.

Physical energy measures: Analysis of participants' reports of physical energy as seen in (Figure 15) revealed an effect for time *F*(1,28)= 5.53, p=.026, $\acute{\eta}_p^2$ =. 165, suggesting that participants' physical energy declined in a linear manner as the session progressed. ICC = 0.79 for the rest group. No interaction of time and group membership was observed, *F*(1,28)=1.93, p=.110, $\acute{\eta}_p^2$ =.065.

Physical fatigue measures: Analysis of participants’ reports of physical fatigue as seen in (Figure 16) revealed an effect for time, F(1,28)=9.79, p=.004, $\acute{\eta}_p^2$ =.295, ICC = 0.87for the rest group; suggesting that participants’ physical fatigue increased in a quadratic manner as the session progressed. Analysis also revealed an interaction for time and group, F(1,28)=6.29, p=.001, $\acute{\eta}_p^2$ =.183; suggesting that increases in physical fatigue depended on time and group membership. Post hoc t-tests were used to compare participants’ scores at each time period. The Bonferroni method of adjustment was employed. Analysis revealed a significant group difference for the second time period, t(28)= -3.605, p= .001, showing that the exercise group reported significantly greater physical fatigue.

Mental energy measures: Analysis of mental energy as seen (Figure 17), revealed an effect for time F(1,28)= 12.75, p=.001, $\acute{\eta}_p^2$ = .313, ICC = 0.81 for the rest group, suggesting that participants’ mental energy declined in a linear manner as the session progressed. Analysis did not reveal any interaction of time and group membership, F(1,28)=.43, p=.561, $\acute{\eta}_p^2$ = .015.

Mental fatigue measures: Analysis of mental fatigue as seen in (Figure 18), revealed a difference for time, F(1,28)=9.20,p=.005, $\acute{\eta}_p^2$ = .257, ICC = 0.78 for the rest group; suggesting that participants’ mental fatigue increased in a quadratic manner as the session progressed. Analysis did not reveal any interaction of time and group membership, F(1,28)=1.00, p=.313, $\acute{\eta}_p^2$ = .036.

Figures 2-4 Visual-Discrimination Performance

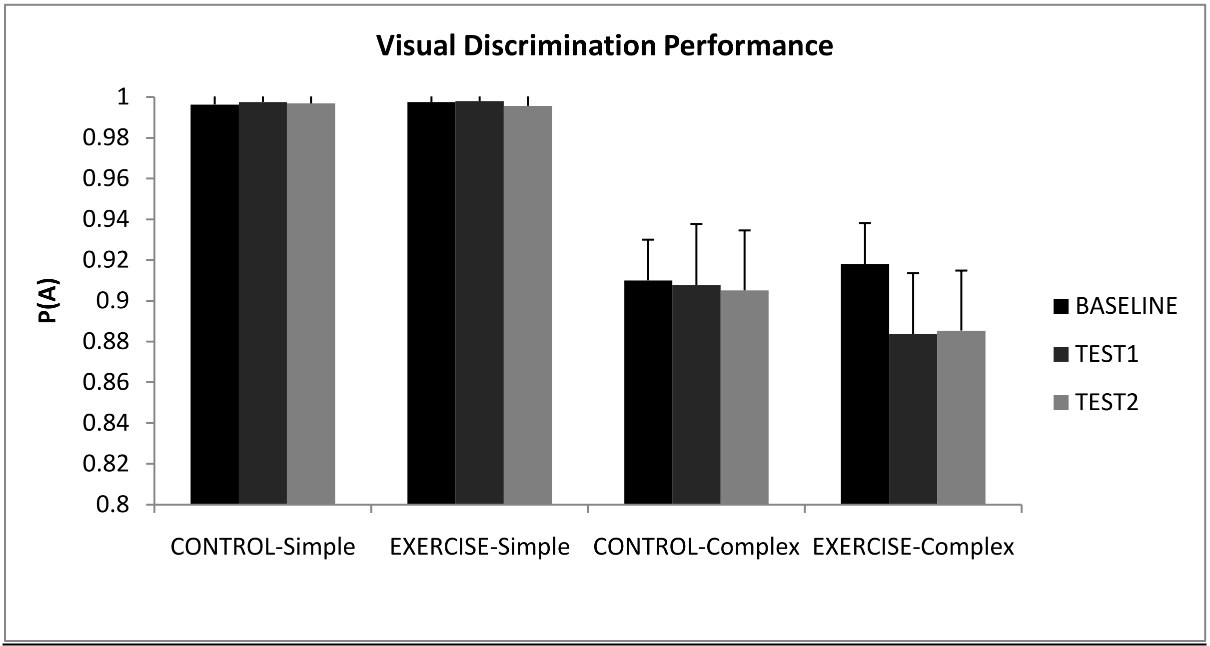

Figure 2. Note. Participants' P(A) for Visual-Discrimination Tests. Mean P(A) proportions for exercise and control groups on simple and complex forms of the visual-discrimination tests administered prior to and following interventions; error bars represent the Standard Error.

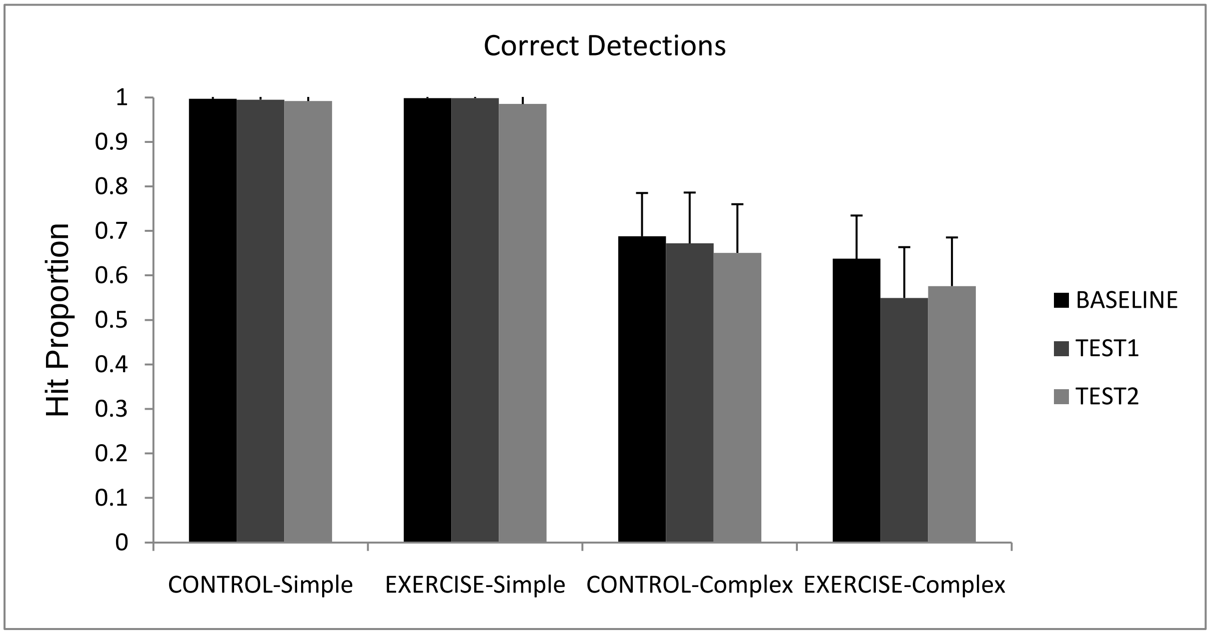

Figure 3. Note. Participants Hits for Visual-Discrimination Tests. Mean Hit proportion for exercise and control groups on simple and complex forms of the visual-discrimination tests administered prior to and following interventions; Error bars represent the Standard Error.

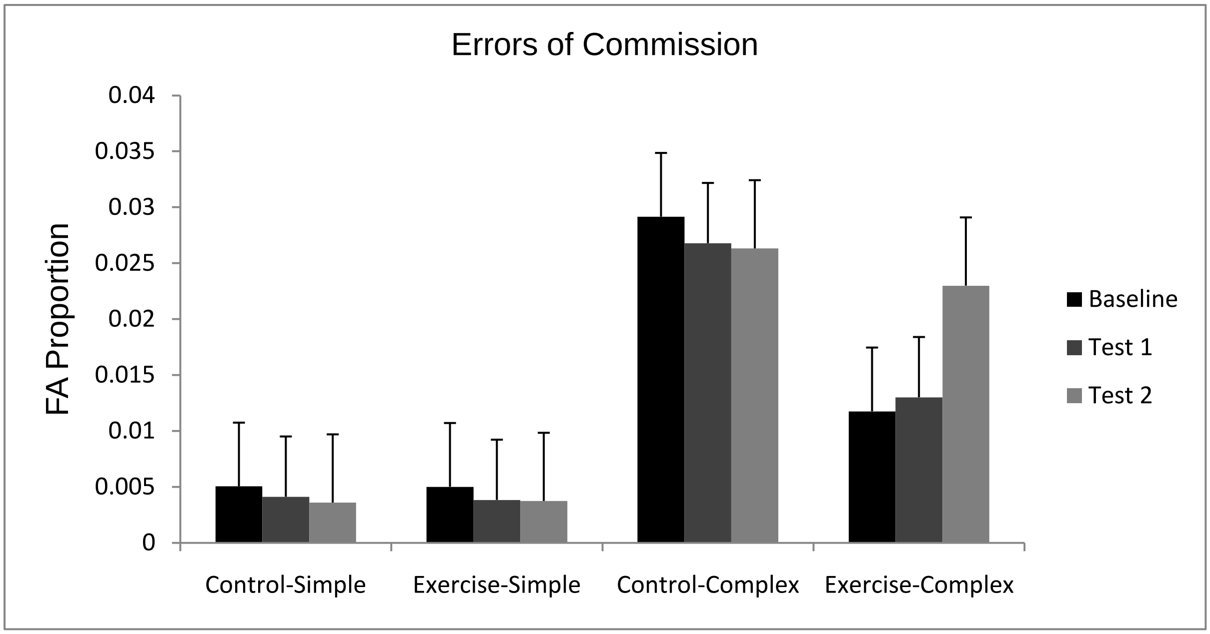

Figure 4. Note. Participants FAs for Visual-Discrimination Tests. Mean False Alarm proportion for exercise and control groups on simple and complex forms of the visual-discrimination tests administered prior to and following interventions; error bars represent the Standard Error.

Figures 5-8: Participants' cognitive vigilance test performance

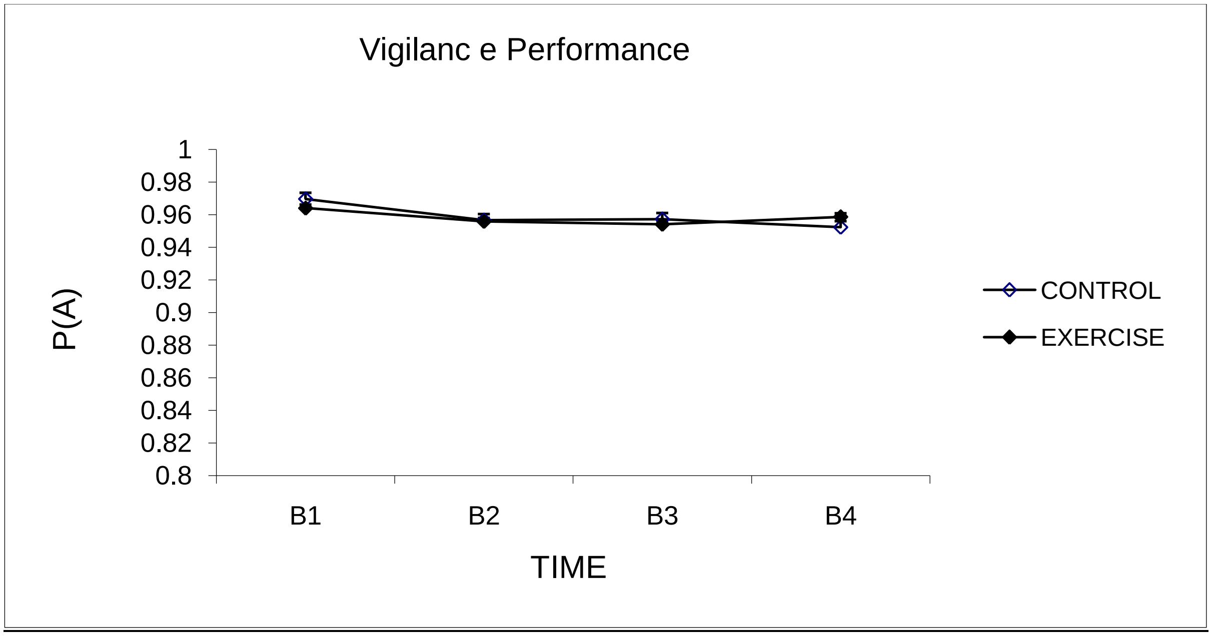

Figure 5. Note. Participants' P(A) for the Cognitive Vigilance Test. Mean performance as measured by P(A) for exercise and control groups during each of four, 10-min periods of the cognitive-vigilance test. Error bars represent the Standard Error. B1, 2, 3, 4 = Blocks 1-4.

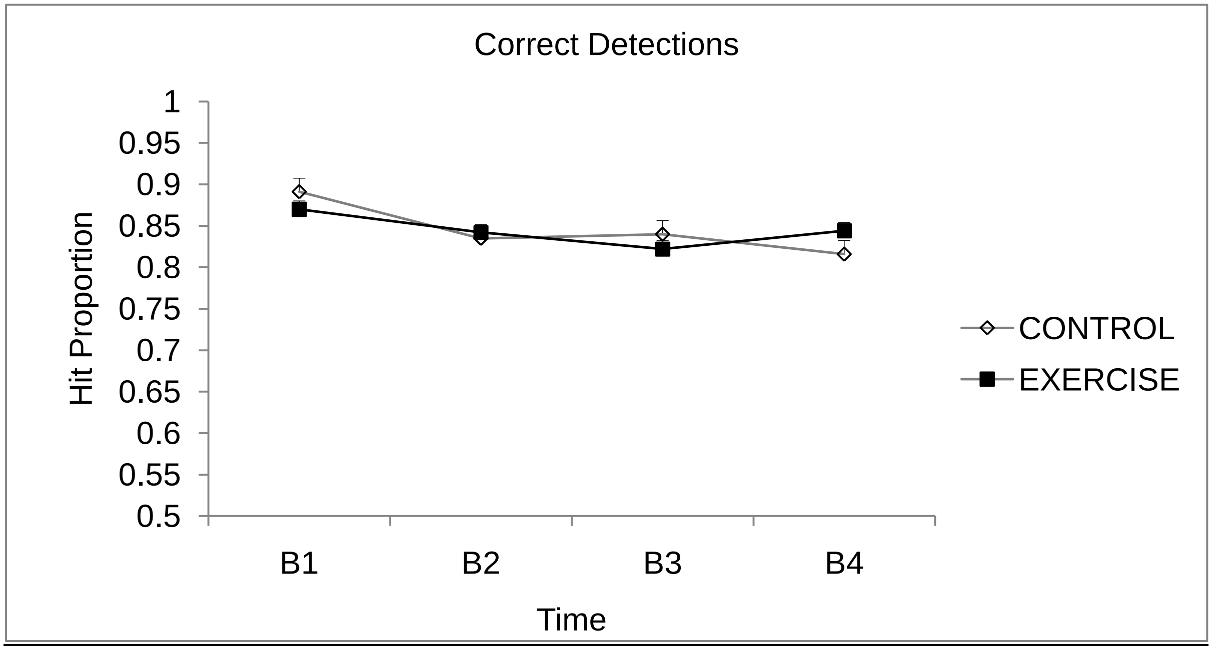

Figure 6. Note. Participants' Hits for the Cognitive Vigilance Test. Mean Hit proportion for exercise and control groups during each of four, 10-min periods of the cognitive-vigilance test. Error bars represent the Standard Error. B1, 2, 3, 4 = Blocks 1-4.

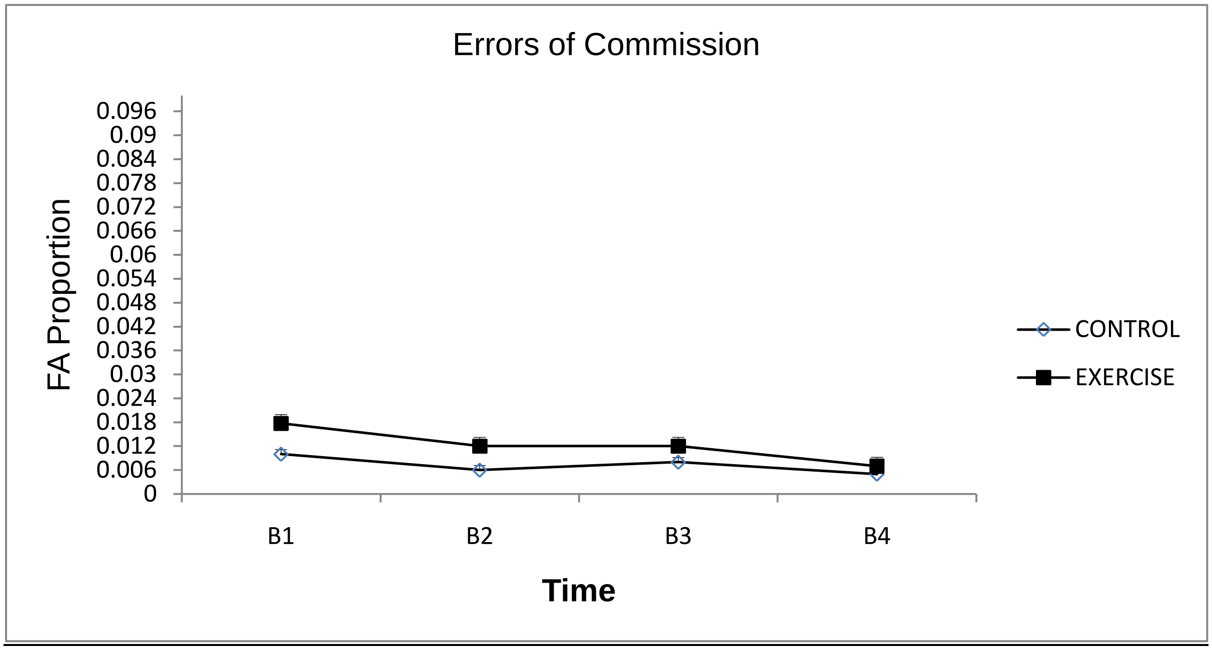

Figure 7. Note. Participants' FAs for the Cognitive Vigilance Test. Mean False Alarm proportion for exercise and control groups during each of four, 10-min periods of the cognitive-vigilance test. Error bars represent the Standard Error. FA = False Alarms. B1, 2, 3, 4 = Blocks 1-4.

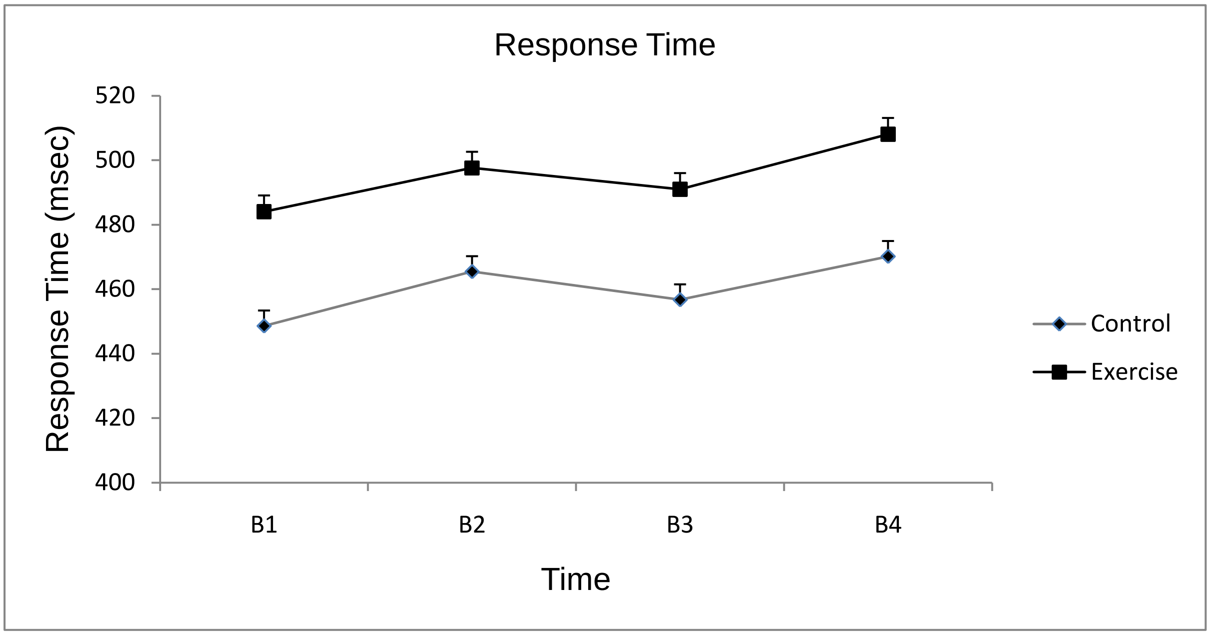

Figure 8. Note. Participants’ Response Times for the Cognitive Vigilance Test. Mean Response Times for all four blocks of the Cognitive-vigilance test; error bars represent the standard error. B1, 2, 3, 4 = Blocks 1-4, msec = milliseconds.

Figures 9 & 10 Group: Participants’ ERP Amplitudes & Latencies for Test 1 and Test 2

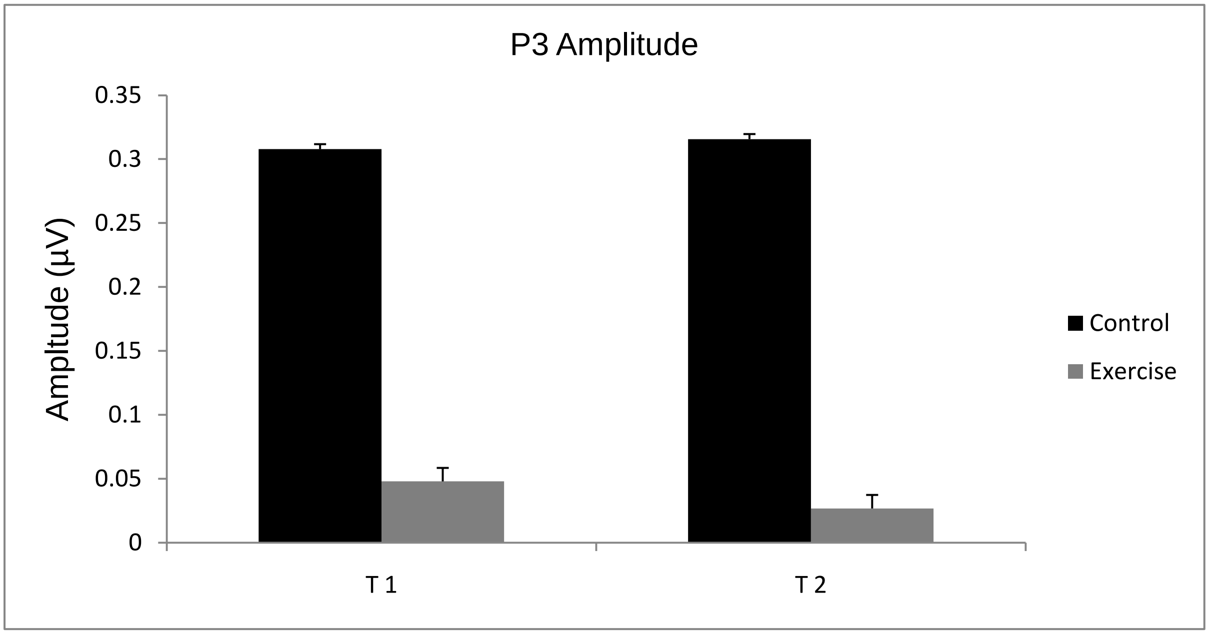

Figure 9. Note. Participants' P3 Amplitudes. Mean P3 amplitudes over Pz for Test 1 and Test 2; μV = microvolt. Test1= second administration of the Visual-Discrimination test. Test2 = third administration of the Visual-Discrimination test. Error bars represent the Standard Error.

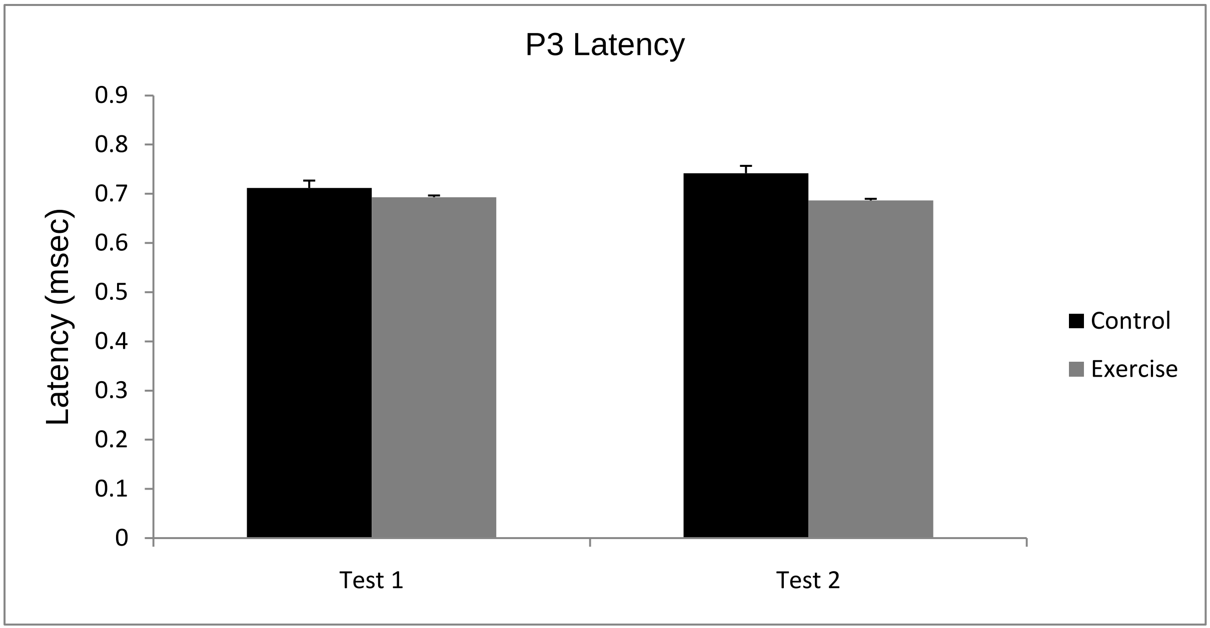

Figure 10. Note. Participants' P3 Latency. Mean P3 Latency over site Pz for Test 1 and Test 2. Test1= second administration of the Visual-Discrimination test. Test2 = third administration of the Visual-Discrimination test. Error bars represent the Standard Error, msec. = milliseconds.

Figures 11-14: Participants' ERP grand averages

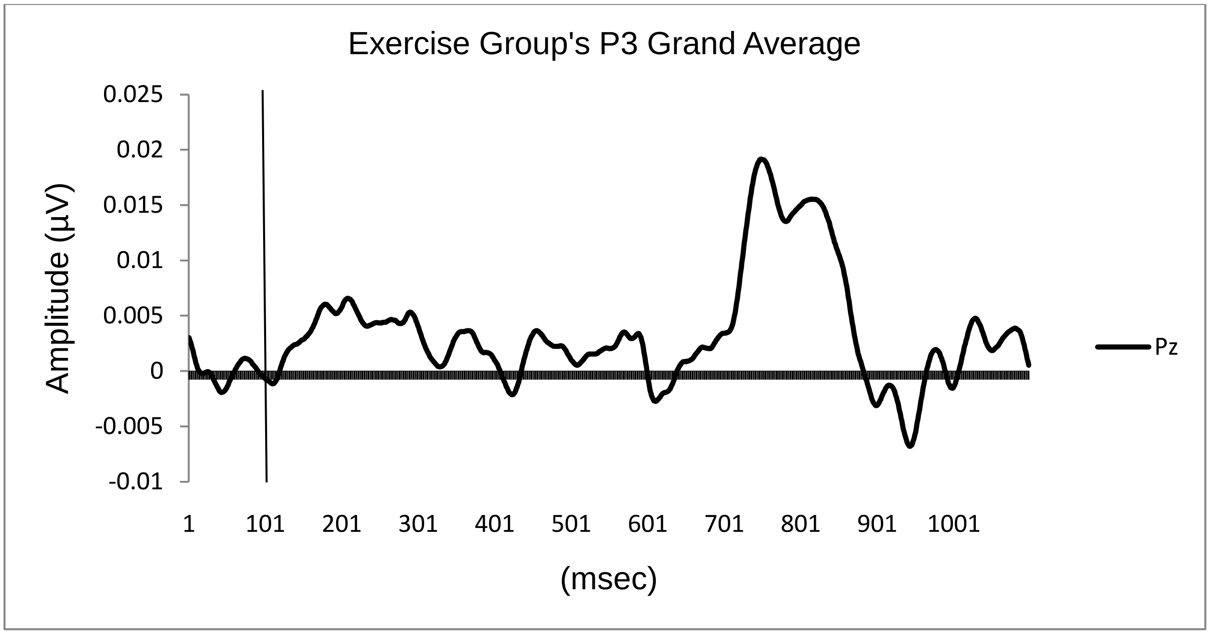

Figure 11. Exercise Group’s P3 Grand Average for Test 1; µV= microvolt, msec. = milliseconds.

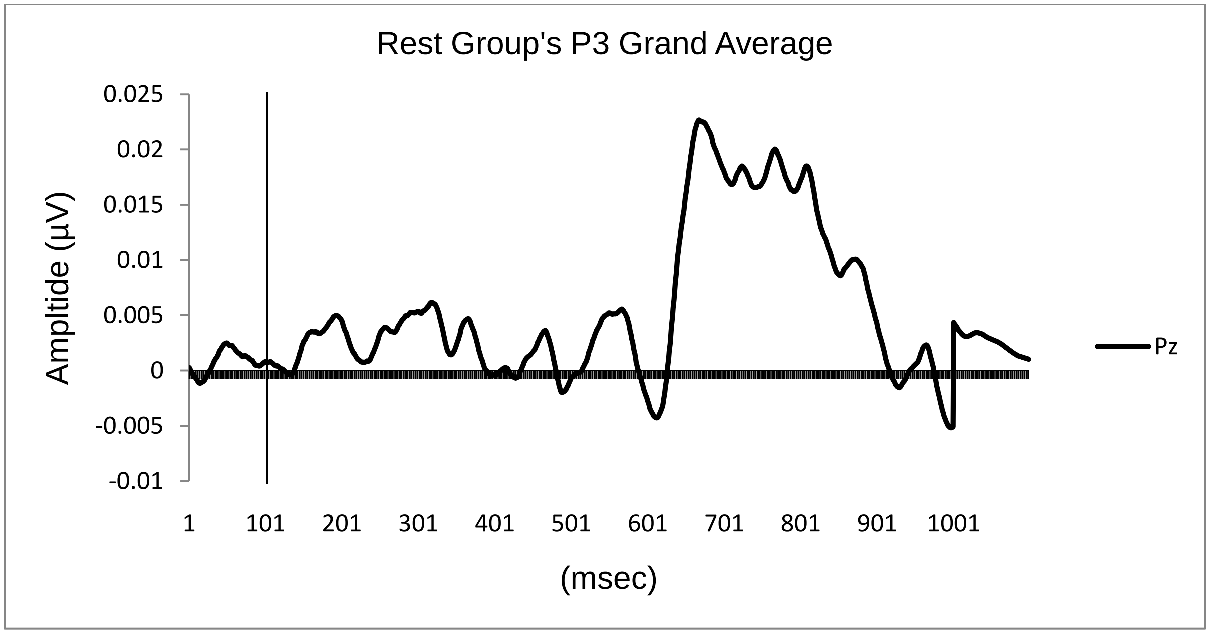

Figure 12. Note. Rest Groups' P3 Grand Average for Test1; µV= microvolt, msec. = milliseconds.

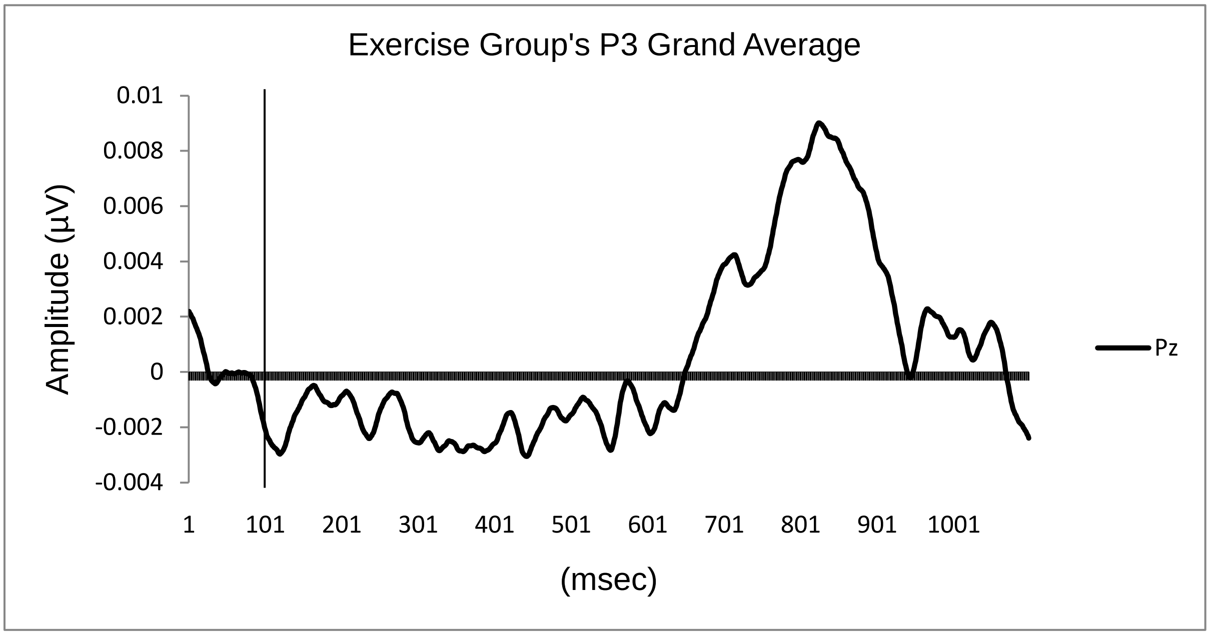

Figure 13. Note. Exercise Groups' P3 Grand Average for Test 2; µV= microvolt, msec. = milliseconds.

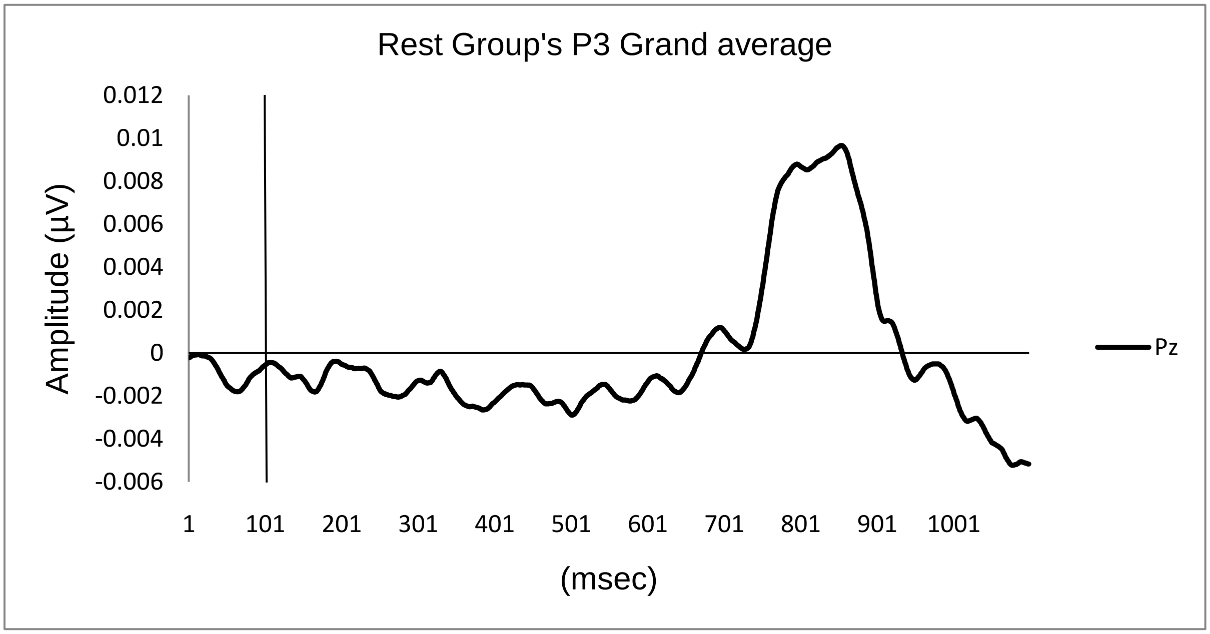

Figure 14. Note. Rest Groups' P3 Grand Average for Test 2; µV= microvolt, msec. = milliseconds.

Figures 15-18: Subjective Trait Energy and Fatigue Data

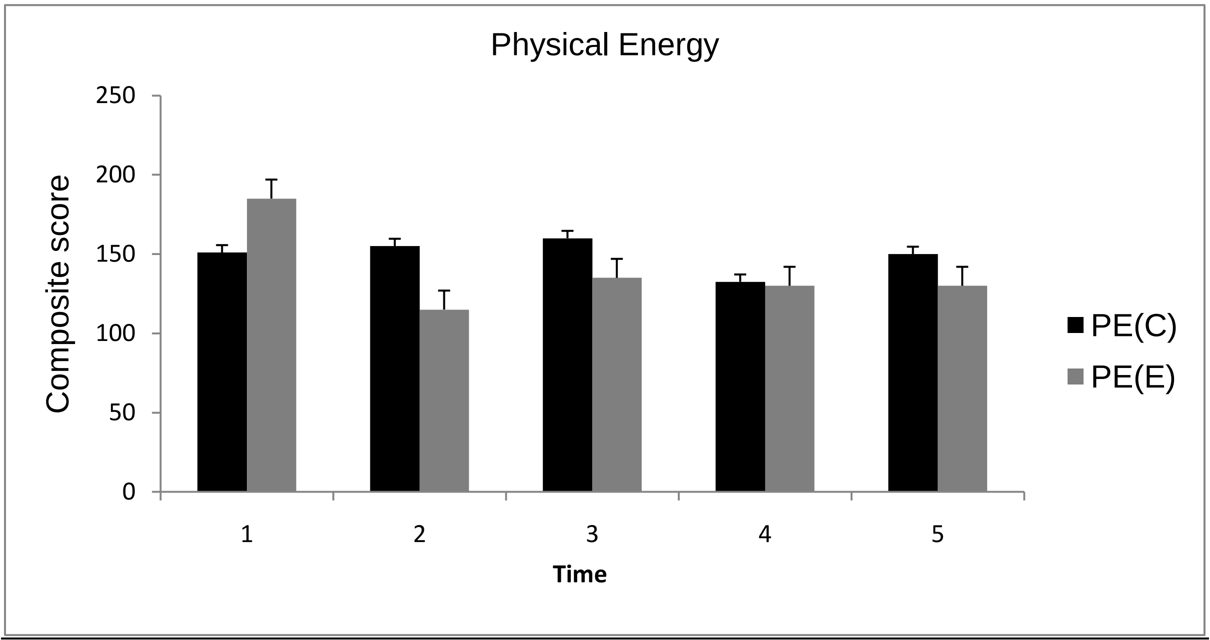

Figure 15. Note. Rest and Exercise groups' Physical Energy ratings. Participants' composite Physical Energy ratings compiled from three separate physical energy indexes. Error bars represent the Standard Error. PE (C) = Physical Energy, Control PE (E) = Physical Energy Exercise.

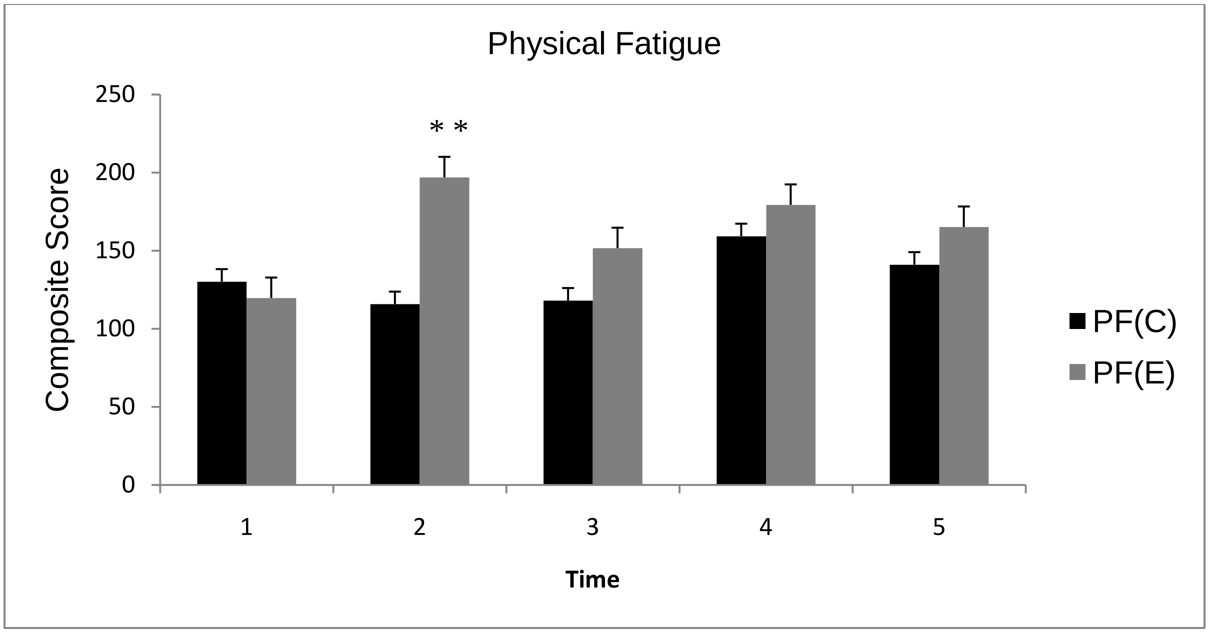

Figure 16. Note. Rest and Exercise groups’ Physical Fatigue ratings; Participants’ composite Physical Fatigue ratings compiled from three separate physical energy indexes. Error bars represent the Standard Error. PF (C) = Physical Fatigue, Control PF (E) = Physical Fatigue Exercise. ** = p<.01.

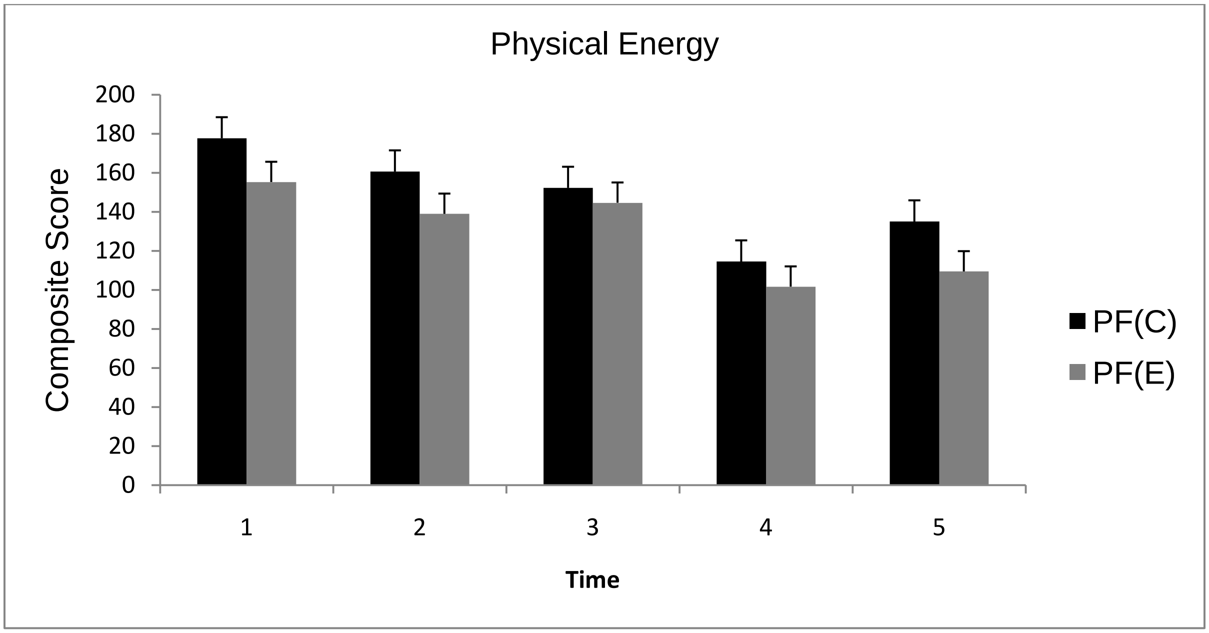

Figure 17. Note. Rest and Exercise groups’ Mental Energy ratings. Participants’ composite Mental Energy ratings compiled from three separate physical energy indexes. Error bars

represent the Standard Error. ME (C) = Mental Energy Control, ME (E) = Mental Energy Exercise.

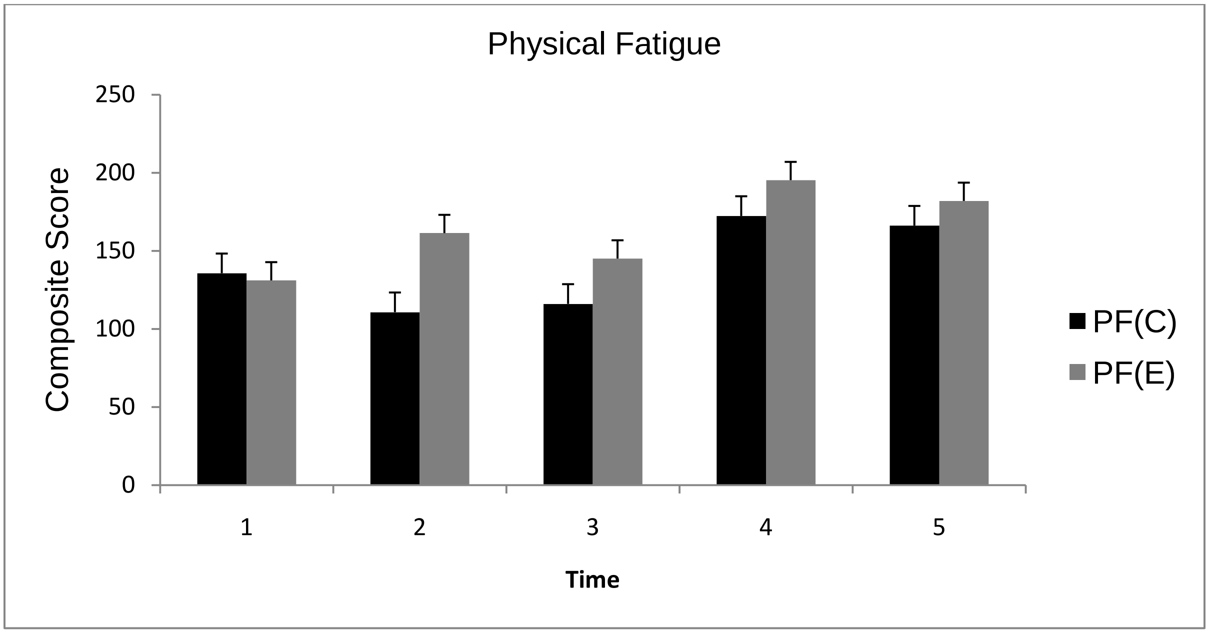

Figure 18. Note. Rest and Exercise groups' Mental Fatigue ratings. Participants' composite Mental Energy ratings compiled from three separate physical energy indexes. Error bars represent the Standard Error. MF (C) = Mental Fatigue Control, MF (E) = Mental Fatigue Exercise.

Chapter 5

DISCUSSION

The purpose of this experiment was to examine the effects of exercise-induced fatigue on young men's and women's cognitive function. The exercise protocol induced fatigue. Participants who completed the 60-minute bout of cycling reported subjectively greater physical fatigue than individuals assigned to a rest control condition. In addition, neurological measures of cortical activity taken during the performance of mental tests were significantly lower for those who exercised than those that rested. Following exercise or control interventions, participants performed a battery of cognitive tests over a 75-minute period. The test battery was composed of a simple and a complex perceptual visual-discrimination test, which were performed prior to and following a 40-minute cognitive vigilance test. Based on a theory of human performance proposed by Hockey (1997), it was predicted that participants who exercised would perform more poorly on tests of perceptual processing than individuals who did not exercise, particularly on test conditions that were complex. It was also predicted that participants' vigilance performance would decline more rapidly for those who exercised as compared to rest.

Similar to previous experiments (Pontifex, Polich & Hillman, 2009), participants' performance was significantly lower on a complex three-stimulus version of the visual-discrimination test as compared to a simple two-stimulus version of the tests. As in the Pontifex et al. (2009) study, participants' accuracy performance was significantly higher during the administrations of the simple version of discrimination test. It appears that perceptual demands of the simple version of the test were minimal and required the allocation of few attentional resources. Under these conditions, physical fatigue effects may have been present but occluded by the observed ceiling effect.

Analysis of the three-stimulus, complex version of the discrimination test provided evidence that support predictions drawn from Hockey's (1997) compensatory-control theory. Participants who exercised, as compared to those who rested, demonstrated significantly poorer performance during the complex version of the test. The perceptual-discrimination tasks used in the present study were characterized by a brief presentation of individual stimuli and required participants to make decisions on a trial-by-trial basis. On each trial of the task, the participant was required to compare the physical size of a circle to the memory of size of the preceding circle. Over repeated trials, decisions concerning the similarity of the physical size of successive stimuli occur relatively automatically and with minimal conscious awareness. Lower-level discriminations based on the physical attributes of stimuli constitute a signal-to-noise problem in which the individual is required to assess and compare the strength of successive stimuli (Evans, Hygge & Bullinger, 1995).

It is plausible that exercise-induced fatigue may alter the neurological signal-to-noise relation that provides the basis for decision making. Support for this interpretation is provided by neurological measures following fatiguing bouts of exercise. In the present experiment, participants who exercised, compared to those who rested, demonstrated significantly lower P3 amplitudes following intervention. Further, participants who exercise continued to evidence decreased P3 amplitudes, compared to those who rested, 75 minutes post intervention. While the ERP data obtained was limited to neurological measures obtained during the simple version of the discrimination test, the significantly lower P3 amplitude of exercisers compared to those who rested builds upon previous evidence suggesting that exercise-induced fatigue alters cortical activity and affects perceptual-discrimination performance. Kamijo and his colleagues (2004a; 2004b, 2007), performed a series of experiments that evaluated the effects of brief acute cycle ergometry on neurological function. Participants in these experiments demonstrated reduced ERP component amplitudes following high intensity cycling as compared to the control and low intensity exercise conditions. Further, Grego et al., (2004) evaluated the effect of long duration cycle ergometry on neurological function. Immediately following exercise termination, participants exhibited extended P3 latencies compared to pre-exercise P3 measures. Based on Hockey's model, it would be expected that physical fatigue lowers the amount of attentional resources one is able to allocate to stimuli, thereby acting to lower P3 amplitude. No group differences were observed for P3 latency during the simple condition of the visual discrimination task. However, physical fatigue commonly affects only one dimension of neurological activity (i.e., either amplitude or latency). The rejection criteria employed in the present study resulted in insufficient data to assess neurological activity during the complex version of the discrimination test. Given that there were only 25 target trials in the complex version of the task, measurement artifacts were problematic. Data collection fidelity may be improved by lengthening the number of trials in the complex version of the test for use in fatigue experiments and by attenuating participants' movements during the test session.

The decrement in exercisers' performance during the complex perceptual task may also be explained in terms of changes in their motivational levels. While plausible, participants' performance during the cognitive-vigilance task suggests that not to be the case. Indeed, even though participants in both exercise and rest groups reported reduced mental energy and more mental fatigue following the cognitive-vigilance test, their performance was maintained across the 40-min test, with no differences in target detection between the two groups. The Bakan vigilance test requires individuals to view a series of successively presented numbers and to maintain information about characteristics of each number (odd or even) in working memory. Unlike lower-level perceptual discrimination tasks, the Bakan test involves the conscious storage and manipulation of symbolic information. Performance of this goal-oriented test would bring the higher-level processes described in Hockey's theory into play. The attentional resources allocated to the conscious processing of symbolic information and the maintenance of performance would be controlled by the individual. While exercise-induced fatigue slowed participants' response times, it did not affect target detection accuracy or errors of commission, suggesting that participants were able to compensate for lower arousal and to maintain task performance at a level comparable to individuals in the rest condition.

Vigilance tests are known to be mentally effortful to perform (Warm, Parasuraman & Mathews, 2008). Cognitive vigilance tasks lasting two hours have been shown to negatively impact participant's performance of subsequent mental tasks and to alter neurological functions (Boksem, Miejman & Lorist , 2006; Lorist, 2008). The mental demands required to perform the 40-min Bakan vigilance test were predicted to negatively impact participants' performance during the second administration of the visual discrimination test. However, no subsequent degradation was observed. It may be that a 40-minute vigil is not sufficiently demanding and that it may require a more prolonged task to affect participants' detection performance.

There were several limitations in the current experiment. First, it was predicted in the present study that participants who exercised, compared to those who rested, would evidence lower P3 amplitudes and longer P3 latencies during both simple and complex versions of the visual-discrimination test. However, measurement artifacts led to rejection of data from numerous trials of both versions of the discrimination test. Per convention (Cohen & Polich, 1997), for each person, a minimum of 20 artifact-free trials was required for data analysis. The rejection criteria led to the exclusion of seven participants' data collected during the simple discrimination test. In addition, recruitment procedures focused on drawing young men and women from Kinesiology and Psychology classes. Additionally, all participants were ages 18-28 with a mean age of 22 which limits the currents results ability to generalize to other age ranges. Further, all of the participants in the current experiment reported a history of engaging in regular physical activity, limiting the current results to generalize to populations who engage in regular physical activity. Additionally, only one type of exercise was evaluated in the current experiment. Further study would be needed to evaluate the effects of acute physical fatigue for other forms of aerobic and anaerobic activity, such as running or weight lifting. Lastly, the physical fatigue in the current experiment was minimal. Further research could evaluate the effects of physical fatigue over a period of several successive days.

In summary, young adults' perceptual discriminability during a complex visual-discrimination task was degraded following a single 60-minute cycling bout. Further, those who exercised demonstrated evidenced slower response times to targets during a 40-minute cognitive-vigilance test than those who rested. These behavioral data indicate that a prolonged bout of aerobic exercise may lower young adults' arousal level. Neurophysiological measures of brain activity and participants' subjective responses to questionnaires provide additional evidence for the reduction in arousal produced by a relatively long period of exercise. The evidence obtained in this experiment and in other similar laboratory-based experiments, (Pass & Adam, 1991; McMorris & Keen, 1994; Brisswalter et al., 1995; Hogervost et al., 1996; Cian et al., 2000, Cian et al., 2001; Tomporowski et al., 2007) suggest that physical fatigue produced by a single exercise bout may negatively affect lower-level perceptual processes more than higher-level executive type mental processes. In terms of Hockey's compensatory-control theory, the non-conscious shift of the signal-to-noise ratio produced by stressors may be subtle and insufficient to meet the threshold of the Effort Monitor and to elicit activation of processes in the executive loop of the model. Thus, without the involvement of high-level executive processing and goal-oriented problem solving strategies that lead to compensatory allocation of attentional resources by executive system, perceptual detection performance degrades.

A further consideration is that central fatigue develops gradually. An individual bout may produce a small change in central fatigue, which can be seen in decrements in performance perceptual-type tasks, but not executive tasks. Perhaps following several successive days of extended exercise, performance on both lower-level processing tasks and higher-level processing task may be observed.

The current results are potentially applicable for human performance in occupational settings. Military personnel, for example, are often required to perform both cognitive and sensory discrimination under conditions of physical fatigue. The results of the current study suggest that critical functions such as visual sensory-discrimination and reaction-time could be compromised in military personnel that are minimally physically fatigued. Future research could serve to further clarify the effects of physical fatigue on sensory and cognitive performance tasks in military settings where processing errors carry a high cost.

<u>Tables 1- 3: Sensory and Cognitive Test Performance</u>

Table 1

Participants' Visual-Discrimination Data; participants' mean Percent of Hits and False Alarms for all three administrations of the Visual-Discrimination Test. SD = Standard Deviation.

HITS	Baseline	SD	Test 1	SD	Test 2	SD
Rest-Simple	99.66	.84	99.83	.62	98.66	2.56
Exercise-Simple	99.83	.62	99.50	1.35	99.00	2.00
Rest-Complex	69.86	12.12	63.46	22.76	62.66	20.06
Exercise-Simple	66.40	16.31	58.66	22.42	60.00	17.94
False Alarms	**Baseline**	**SD**	**Test 1**	**SD**	**Test 2**	**SD**
Rest-Simple	.33	.50	.18	.41	.16	.35
Exercise-Simple	.25	.50	.25	.38	.20	.37
Rest-Complex	1.86	2.91	2.20	2.26	1.59	2.63
Exercise-Simple	.83	1.17	.49	1.30	1.29	2.29

Table 2

Cognitive-Vigilance Data; participants' mean Response Times and Standard Deviations for all four blocks of the Cognitive Vigilance Test. SD = Standard Deviation.

Block	Group	Mean	SD

1	Rest	452.08	38.52
	Exercise	484.03	54.06
2	Rest	466.31	44.56
	Exercise	497.57	56.60
3	Rest	454.94	40.15
	Exercise	490.96	51.27
4	Rest	467.77	55.19
	Exercise	508.07	60.89

Table 3

Cognitive-Vigilance Response Times; participants' Mean Percent of Hits and False Alarms for all four blocks of the Cognitive Vigilance Test. FAs = False Alarms. SD = Standard deviation.

BLOCK	Group	Mean Hits	SD	Mean FAs	SD
1	Rest	89.11	7.39	1.00	.03
	Exercise	87.0	22.34	1.77	.82
2	Rest	83.50	10.57	.6	.30
	Exercise	84.20	21.66	1.20	1.27
3	Rest	84.00	12.66	.80	.27
	Exercise	82.25	22.82	1.2	.83
4	Rest	81.60	17.03	.50	.25
	Exercise	84.41	22.87	.70	.68

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A

CONSENT FORMS

Exercise Condition

I, __________________, agree to participate in the research titled, **Effects of Acute Aerobic Exercise on Attention**, which is being conducted by Dr. Phillip Tomporowski (706-542-4183) of the Department of Kinesiology at the University of Georgia. I understand that this participation is entirely voluntary; I can refuse to participate or I can withdraw my consent at any time without penalty or loss of benefits to which I am otherwise entitled and have the results of the participation, to the extent that it can be identified as mine, returned to me, removed from the research records, or destroyed.

The primary purpose of this study is to assess the effects of aerobic exercise on selected and sustained attention.

If I volunteer to take part in this study, I will be asked to attend three laboratory sessions, one lasting about 90 minutes and the other about 180 minutes.

During the laboratory session #1, I will be asked to do the following things:

1) Complete questionnaire about my health and physical activity which will take about 10 minutes.

2) Learn to perform sensory/ information processing tasks, which will take about 20 minutes.

3) Learn about how measures of brain activity are taken, which will take about 10 minutes.

4) Perform a test on a stationary cycle ergometer designed to measure my aerobic capacity, which will take about 20 minutes.

During the second laboratory session, I will be asked to do the following things:

1) Complete questionnaires concerning my recent behaviors and about how I feel, which will take about 10 minutes.

2) Have heart rate electrodes placed on my chest and cycle for 60 minutes on a stationary ergometer.

3) Provide reports of my feelings of energy and fatigue.

4) Have electroencephalography (EEG) electrodes placed on my scalp, which will take about 15 minutes.

5) Sit in front of a computer screen and carry out three tests of attention, which will be completed in about 80 minutes.

I will benefit from the study by being given information concerning my aerobic fitness, and by contributing to the advancement of the fields of exercise science and psychology.

I am aware that the test of aerobic capacity requires moderate exercise. I may experience muscular or systemic discomfort while exercising on the cycle ergometer. I am aware that during exercise I will be closely monitored for signs of over exertion and exercise will be terminated immediate if signs of over exertion develop (headache, nausea, dizziness, or mental disorientation). Aerobic exercise may cause circulatory problems in some individuals. While it is extremely rare in young people, I realize there is a risk of sudden cardiac death during vigorous exercise. Estimates are 1 death/year for 122,000 men and 769,000 women. No risk is expected during other test sessions, but I may experience discomfort when exercising or sitting on the cycle ergometer.

As a participant, I assume certain risk of physical injury. UGA will exercise all reasonable care to protect me from harm as a result of my participation. In the event of an injury as an immediate and direct result of my participation, UGA’s sole responsibility is to provide immediate, emergency care, and as necessary to transport me to an appropriate facility if additional care is needed. As a participant, I do not give up or waive any legal rights. In the event I am injured as a result from research procedures, Dr. Phillip Tomporowski (706-542-4183) will be contacted immediately.

No individually identifying information about me, or provided by me during the research, will be shared with others without my written permission, except if it is necessary to protect my welfare (for example, if I were injured and need physician care) or if required by law. During the course of the study, all of my data forms, questionnaires, and computer files will be stored in a secure filing system under the supervision of Dr. Phillip Tomporowski.

The investigators will answer any further questions about the research, now or during the course of the project. In addition, I am aware that I can contact Dr. Tomporowski at 706-542-4183 for information about the research.

My signature below indicates that the researchers have answered all of my questions to my satisfaction and that I consent to volunteer for this study. I have been given a copy of this form.

_____________________	_______________________	___________
Name of Researcher	Signature	Date

Telephone: (706)542-4183

Email: ptomporo@uga.edu

____________________________	_________________________	__________
Name of Participant	Signature	Date

Please sign both copies, keep one and return the other to the investigator.

Additional questions or problems regarding your rights as a research participant should be addressed to the Human Subjects Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706)542-3199; e-Mail Address IRB@uga.edu

Rest Condition

I, ________________, agree to participate in the research titled, **Effects of Acute Aerobic Exercise on Attention**, which is being conducted by Dr. Phillip Tomporowski (706-542-4183) of the Department of Kinesiology at the University of Georgia. I understand that this participation is entirely voluntary; I can refuse to participate or I can withdraw my consent at any time without penalty or loss of benefits to which I am otherwise entitled and have the results of the participation, to the extent that it can be identified as mine, returned to me, removed from the research records, or destroyed.

The primary purpose of this study is to assess the effects of aerobic exercise on selected and sustained attention.

If I volunteer to take part in this study, I will be asked to attend three laboratory sessions, one lasting about 60 minutes and the other about 180 minutes.

During the laboratory session #1, I will be asked to do the following things:

1) Complete questionnaire about my health and physical activity which will take about 10 minutes.
2) Learn to perform sensory/ information processing tasks, which will take about 20 minutes.
3) Learn about how measures of brain activity are taken, which will take about 10 minutes.

During the second laboratory session, I will be asked to do the following things:

1) Complete questionnaires concerning my recent behaviors and about how I feel, which will take about 10 minutes.

2) Have heart rate electrodes placed on my chest and cycle for 60 minutes on a stationary ergometer.

3) Provide reports of my feelings of energy and fatigue.

4) Have electroencephalography (EEG) electrodes placed on my scalp, which will take about 15 minutes.

5) Sit in front of a computer screen and carry out three tests of attention, which will be completed in about 80 minutes.

I will benefit from the study by learning about scientific methods, electroencephalography and by contributing to the advancement of the fields of exercise science and psychology.

No risk is expected during the test session.

As a participant, I assume certain risk of physical injury. UGA will exercise all reasonable care to protect me from harm as a result of my participation. In the event of an injury as an immediate and direct result of my participation, UGA's sole responsibility is to provide immediate, emergency care, and as necessary to transport me to an appropriate facility if additional care is needed. As a participant, I do not give up or waive any legal rights. In the event I am injured as a result from research procedures, Dr. Phillip Tomporowski (706-542-4183) will be contacted immediately.

No individually identifying information about me, or provided by me during the research, will be shared with others without my written permission, except if it is necessary to protect my welfare (for example, if I were injured and need physician care) or if required by law. During the course of the study, all of my data forms, questionnaires, and computer files will be stored in a secure filing system under the supervision of Dr. Phillip Tomporowski.

The investigators will answer any further questions about the research, now or during the course of the project. In addition, I am aware that I can contact Dr. Tomporowski at 706-542-4183 for information about the research.

My signature below indicates that the researchers have answered all of my questions to my satisfaction and that I consent to volunteer for this study. I have been given a copy of this form.

Name of Researcher	Signature	Date

Telephone: (706)542-4183

Email: ptomporo@uga.edu

____________________________ __________________________ __________

Name of Participant Signature Date

Please sign both copies, keep one and return the other to the investigator.

Additional questions or problems regarding your rights as a research participant should be addressed to the Human Subjects Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706)542-3199; e-Mail Address IRB@uga.edu.

B

SELF-ADMINISTERED PRE-EXERCISE MEDICAL HISTORY FORM

SELF-ADMINISTERED PRE-EXERCISE MEDICAL HISTORY

Date administered__________

ID _______________ Sex ______________ Age ____________ Date of Birth _________

Researcher’s name: _____________________

1. Do you have or have you ever had: (check if yes)

_____ Pain in your heart or chest

_____ Heart attack

_____ Rheumatic fever (Recent)*

_____ Diseases of the arteries

_____ Varicose veins

_____ Heart murmur (Recent)

_____ Any heart problem

_____ Abnormal EKG

_____ Extra or skipped heart beats

_____ Coughing of blood

_____ Anemia

_____ Diabetes

_____ Epilepsy (Recent)

_____ Bronchitis

_____ Asthma (Recent)

_____ Pneumonia (Recent)

_____ Abnormal chest x-ray

_____ Other lung diseases

_____ Phlebitis

_____ Dizziness or fainting spells

_____ Stroke

_____ High blood pressure

_____ Badly swollen ankles

_____ Cough on exertion (Recent)

_____ Heat-related illness (severe muscle cramps, heat exhaustion, heat stroke)

_____ Kidney disease

_____ Operations (Recent)

_____ Injuries to back, arm, legs or joints (Recent)

_____ Back pain (Recent)

_____ Swollen, stiff or painful joints

_____ Arthritis of arms or legs

_____ Scarlet fever

_____ Sickle cell trait/disease

_____ Liver disease

_____ Hypothyroidism

* Recent = within the past 12 months

Explanation or comments: ____

____

2. List any medicines, drugs, and herbal products or dietary supplements you are now taking:

____

____

3. Date of last complete medical exam: __________ Were results normal? _________

If no, explain: ____

4. Do you know of any medical problem that might make it dangerous or unwise to participate in vigorous exercise? Yes ______ No ______

If yes, explain: ____

5. Are you currently involved in a regular exercise or physical training program? If yes, indicate type and amount of exercise/training.

____

6. Do you experience discomfort, shortness of breath or pain with moderate exercise? Yes ____ No __

7. Have you been diagnosed with a Learning Disability?

Yes ____ No _____

If yes, explain: ____

8. Explain any other significant medical problems you consider it important for us to know:

____

____

9. Do you have any visual problems? e.g., are you near sighted (Myopic)?

Yes _____No _____

If yes, explain: ____

10. Do you wear corrective lenses?

Yes ____ No ____

If yes, explain: ____

11. What is your dominant hand? Right ______ Left _____ Ambidextrous _________

C

PHYSICAL ACTIVITY HISTORY FORM

Physical Activity History:

Date administered ___________

ID ________________ Investigator's name ____________

1. Did you participate in high school activities? Yes _____ No ________

If yes, what activities? ____

2. Did you participate in college athletic activities? Yes _____ No _________

If yes, what activities? ____

3. Are you currently competing in athletics? Yes _____ No ________

Describe: ____

4. Do you engage regularly in vigorous physical activity? Yes _______ No ____

If yes, describe the type and amount of activity below

Types of activity	Frequency (days/week)	Duration (minutes)
__________________	____________	________________
__________________	____________	________________
__________________	____________	________________

5. Do you use interval training? Yes _______ No __________

6. What is your perception of the intensity of exercise during a typical workout?

Mild ___ Moderate ____ Hard _______ Very Hard ________

7. How long have you been involved in this or a more stressful exercise program?

______ years

D

24-HOUR HISTORY QUESTIONAIRE

Date Administered: ________________

ID: ________________________

Session #: 2 / 3 (Circle)

Time: ________________

1. How much sleep did you get last night? (please circle one)

1 to 4 hrs / 4 to 6 hrs 6 to 8 hrs / 8 to 10+ hrs

2. How much sleep do you normally get each night? (please circle one)

1 to 4 hrs / 4 to 6 hrs 6 to 8 hrs / 8 to 10+ hrs

3. When did you last have (and amount):

Coffee: ____________ _________

Tea : ____________ _________

Soft drink: _____________ __________

Drugs (including aspirin): ____________ _________

____________ _________

Alcohol: __________ _________

4. What sort of physical activity did you perform yesterday?

5. What sort of physical activity have you performed today?

6. Describe your general feelings by checking **one** of the following:

_______ excellent

_______ very good

_______ good

_______ neither good or bad

_______ bad

_______ very bad

_______ terrible

E

PROCEEDURE FORM (EXERCISE CONDITION)

Ergometer Data and Procedure

Exercise Condition

Name ___________________________________ Number ____________

Date _____________ Time ___________ Tester __________________________

TIME (SEC) PROCEDURES RPE HR

Paper work

Place on HR monitor

Baseline Odd-Ball Task

Instructions/Adjustments

Begin pretest

Obtain RPE/HR ______ ______

Start Timer

0:00 Begin warm up (30% VO

4:30	Inform exercise phase will begin soon		
5:00	Begin exercise phase (90% VT)		
10:00	Obtain RPE/HR	______	______
20:00	Obtain RPE/HR	______	______
30:00	Obtain RPE/HR		
40:00	Obtain RPE/HR	______	______
50:00	Obtain RPE/HR	______	______
60:00	Obtain RPE/HR	______	______

-Administer Energy and Fatigue Scale

-Prepare for EEG

-Administer Odd-ball # 1

-Administer Energy and Fatigue Scale

-Administer Cognitive Vigilance test

-Administer Energy and Fatigue Scale

-Administer Odd-ball # 2

-Administer Energy and Fatigue Scale

-Remove EEG equipment and clean participant

-Debrief Participant

F

PROCEEDURE FORM (REST CONDITION)

Procedure

Rest Condition

Name ____ Number ______________

Date _______________ Time _____________ Tester ______________________________

TIME (SEC)	PROCEDURES	RPE	HR
	Paper work		
	Place on HR monitor		
	Baseline Odd-Ball Task		
	Instructions/		
	Participant lies down		
	Obtain RPE/HR	______	______

Start Timer

10:00 Obtain RPE/HR ______ ______

20:00 Obtain RPE/HR ______ ______

30:00 Obtain RPE/HR

40:00 Obtain RPE/HR ______ ______

50:00 Obtain RPE/HR ______ ______

60:00 Obtain RPE/HR ______ ______

-Administer Energy and Fatigue Scale

-Prepare for EEG

-Administer Odd-ball # 1

-Administer Energy and Fatigue Scale

-Administer Cognitive Vigilance test

-Administer Energy and Fatigue Scale

-Administer Odd-ball # 2

-Administer Energy and Fatigue Scale

-Remove EEG equipment and clean participant

-Debrief Participant

G

RATING OF PERCIEVED EXERTION SCALE

Instructions for Borg Rating of Perceived Exertion (RPE) Scale

While doing physical activity, we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion.

Look at the rating scale below while you are engaging in an activity; it ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from below that best describes your level of exertion. This will give you a good idea of the intensity level of your activity, and you can use this information to speed up or slow down your movements to reach your desired range.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then give a number.

6 No exertion at all

7

Extremely light (7.5)

8

9 Very light

10

11 Light

12

13 Somewhat hard

14

15 Hard (heavy)

16

17 Very hard

18

19 Extremely hard

20 Maximal exertion

Anchors:

9 corresponds to "very light" exercise. For a healthy person, it is like walking slowly at his or her own pace for some minutes

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.