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THE EFFECTS OF AN EXHAUSTIVE BOUT OF EXERCISE ON NEUROCOGNITIVE PERFORMANCE IN RECREATIONAL ATHLETES

By

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ABSTRACT

THE EFFECTS OF AN EXHAUSTIVE BOUT OF EXERCISE ON NEUROCOGNITIVE PERFORMANCE IN RECREATIONAL ATHLETES

By

Leigh Jordan Weiss

Purpose: The purpose of the study is to examine the effects of exhaustive exercise on cognitive function in recreational athletes.

Methods: A total of 102 subjects (48 control, 54 experimental) volunteered for this study. All subjects were administered a practice and baseline ImPACT test. Subjects in the experimental group were asked to perform an exhaustive bout of exercise to VO_2 max. The control group was asked to remain at rest for fifteen minutes. Both groups were then administered a post-test, and a follow-up three days later.

Results: Results revealed significant differences for the experimental group on the verbal memory composite score(p = .03), immediate recall memory scores (p = .00), and delayed recall memory scores (p = .00).

Conclusion: Results of this study suggest exhaustive exercise has a significant impact on cognitive function. As such, it is recommended that ImPACT should not be administered immediately after practice, competition, or removal from play after sustaining a concussion.

So many of our dreams at first seem impossible, then they seem improbable, and then, when we summon the will, they soon become inevitable.

- Christopher Reeve

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CHAPTER 1

INTRODUCTION

Overview of Problem

Neuropsychological testing has become a common method for assessing cognitive function in athletes who suffer a concussion (Collins, Grindel, Lovell, Dede, Moser, Phalin, et al., 1999). Computer-based neuropsychological testing allows the sports medicine team to track recovery, symptom resolution, and assist with establishing return-to-play criteria (Erlanger, Saliba, Barth, Almquist, Webright, & Freeman, 2001). Despite the increased utilization of this method, considerable debate exists among sports medicine professionals on the time sequence for baseline and/or follow-up neuropsychological testing. Currently, some medical practitioners administer a baseline and follow-up neuropsychological test after practice or competition, while athletes are still in an exerted state. Others administer the test either before practice or 24 hours after an athlete has sustained a concussion. To date, no studies have examined if physical exertion impairs an athlete's cognitive function using the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) neuropsychological battery.

Gender differences in cognitive performance have been reported for verbal memory perceptual motor speed, and visualspatial tasks (Kimura & Clark, 2002; Lewis and Kamptner, 1987). Weiss, Kemmler, Deisenhammer et al. (2003), found that females perform better on verbal memory and perceptual motor speed compared to males. Conversely, males perform better on visuospatial tests than females. Similarly, Barr (2003) reported female athletes performed better on verbal initiation compared to male athletes. Because womens' sports participation has expanded significantly during the past decade and brain function differs between genders, it is important to determine if gender differences on neuropsychological function exist after an intense bout of exercise.

Significance of Problem

A common injury associated with athletics is a concussion. Returning the athlete to participation when cognitive deficits still exist can lead to cumulative neurocognitive dysfunction and increase the potential for further injury (Evans, 1994; Kelly, 1995). It is for this reason that proper evaluation and management are critical. Preseason baseline neuropsychological testing has become a common practice in sport and is imperative in order to recognize neurocognitive impairments and changes following brain injury (Collins, et al., 1999). Neuropsychological testing provides an objective means to assess symptoms and cognitive deficit following such injuries.

Previous research has shown that fatigue prior to postural-stability testing decreases balance performance (Wilkins, Valovich, Perrin, & Gansneder, 2004). Balance deficits are only one component to concussion evaluation and return-to-play decision. It is important to examine cognitive function and how it is affected by physical exertion. Research has been conducted to determine the effects of exertion on various measures of cognitive function (Tomporowski, 2003), but results have been inconsistent and contradictory. No study to date has examined the effects of an exhaustive bout of exercise to maximal oxygen uptake (VO_2 max) on cognitive function using the ImPACT neuropsychological test battery.

Statement of Problem

The purpose of this study is twofold. First, to examine the effects of exhaustive exercise to VO_2 max on cognitive function in recreational athletes. Second, to determine if gender differences exist in cognitive function following an exhaustive bout of exercise to VO_2 max.

Research Questions

1. Does exhaustive exercise to VO_2 max have an effect on verbal and visual memory, reaction time, motor processing speed, and impulse control?

2. Do male and female recreational athletes exhibit differences in cognitive function following an exhaustive bout of exercise to VO_2 max?

Definitions

Cognitive Functioning: The ability to use reasoning, judgment, memory, and perception effectively and in a timely manner (Saladin, 2001).

Concussion: Derived from the Latin word *concussus*, which means to shake violently. Described as an injury to the head characterized by immediate and transient impairment of neural function (Cantu, 2001).

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT): A computerized neuropsychological test battery designed to assess sports-related concussion (Lovell, Collins, Iverson, Johnston, & Bradley, 2004).

Maximal Oxygen Uptake (VO_2 Max): The highest rate at which oxygen can be taken up and utilized by the body during exercise by an individual (Bassett & Howley, 2000).

Recreational athlete: Someone who participates in sport or physical activity 2-3 times per week (Bing, Herman, Preston, Lu, Kirkendall, & Garrett, 2004).

Respiratory Exchange Ratio (RER): Described as the volume of carbon dioxide produced divided by the volume of oxygen consumed (Howley, Bassett, & Welch, 1995).

CHAPTER 2

LITERATURE REVIEW

Neuropsychological Testing

Neuropsychological testing involves the assessment of cognitive abilities such as memory, reaction time, attention, and visuospatial skills (Randolph, McCrea & Barr, 2005). Tests for examining cognitive function are often administered in groups, called batteries (Barr, 2001). Recently, neuropsychological testing has evolved from the traditional paper and pencil to computer-based methods.

Computerized neuropsychological testing has many advantages compared to the old paper and pencil tests. Computerized testing allows for more precise measuring of reaction time, measuring within .01 seconds. Computerized testing guarantees consistency in administration and utilizes less manpower to test a greater number of subjects (Pellman, Lovell, Viano, Casson, & Tucker, 2004). Additionally, computerization allows for client control of visual and auditory features such as color or animation (Schatz & Zillmer, 2003). It has been reported that computerized forms of neuropsychological test batteries are designed to reduce practice effects (Schatz & Zillmer, 2003). Neuropsychological testing done in computer-based format allows for an increased security in test data and computerized storage. Finally, administering a computer-based neuropsychological test reduces disposable materials, and allows decrease cost for supplies (Schatz & Browndyke, 2002).

Limitations are also reported with computerized neuropsychological testing. The computer-based interface of the neuropsychological test battery may further cognitively tax those individuals with preexisting attentional and concentration difficulties (Schatz & Zillmer, 2003). In addition, computerized testing may create anxiety in the patient (Browndyke, Albert, Malone, Schatz, Paul, Cohen et al., 2002). During computer-based neuropsychological testing, face-to-face interaction between the patient and the clinician is limited which may lead to failure of the clinician to pick out certain symptoms and may lead to misdiagnoses (Space, 1981). Additionally, Schatz & Zillmer (2003) report that software developers often fail to meet the validity and reliability guidelines set by the American Psychological Association.

Over the past two decades, physicians and athletic trainers have become more interested in utilizing neuropsychological testing in efforts to understand the cognitive and behavioral effects of an athlete following a cerebral concussion (Schatz & Zillmer, 2003). Neuropsychological testing assists medical professionals in understanding both structures of the brain and processes associated with concussion symptoms and post-concussion syndrome. Additionally, neuropsychological testing has been used by sports medicine professionals as a guide to establish return-to-play criteria (Collie, Maruff, McStephen, & Darby, 2003). Randolph, McCrea, and Barr (2005) describe five criteria for validating a sports neuropsychological test battery. These include (1) establishing test-retest reliability, (2) establishing sensitivity, (3) validity, (4) establishing a method for classifying impairment, and (5) determining clinical utility.

There are three main computerized programs that have been developed and are being marketed to athletic programs to better understand neurocognitive function: ImPACT (University of Pittsburgh, Pittsburgh, PA), CogSport (CogState Ltd, Victoria, Australia), and Headminder Concussion Resolution Index (Headminder, Inc, New York, NY). A fourth computerized neuropsychological program called Automated Neuropsychological Assessment (ANAM) has been developed by the United States Government for military use only (Randolph, McCrea, & Barr, 2005).

Physicians and athletic trainers are continually challenged by decisions of when to return athletes to participation following a concussion. With the ability of computerized neuropsychological test batteries to be more sensitive to subtle changes, these tests have become particularly important in the area of sports concussion (Schatz & Zillmer, 2003). Baseline testing has become a common practice and a powerful assessment tool in athletics (Schatz & Zillmer, 2003). Moreover baseline testing allows clinicians to compare pre- and post-concussion cognitive test scores in order to determine differences in neurocognitive function following injury.

Baseline testing is a "must" in neuropsychological testing (Grindel, Lovell & Collins, 2001). This practice provides a basis for individual comparison and presents clinicians with an alternative to using normative data. Comparing an athlete with high cognitive function to an average athlete, the clinician may risk returning the athlete to competition too soon. On the contrary, comparing an athlete with low cognitive function to an average athlete, the clinician may keep the athlete out of competition longer than necessary. It is for this reason that the athletes must be compared against their own normal, to ensure a true baseline (Grindel et al., 2001).

Computerized neuropsychological testing should only be one aspect of post-concussion evaluation. This practice should not be used in isolation but in combination with clinical history, reported symptoms, and neuroimaging to obtain a thorough overall assessment of the concussed athlete (Randolph, McCrea, & Barr, 2005; Barr, 2001). More research needs to be done on the reliability and validity of these programs to ensure long-term success of computer-based assessment (Schatz & Zillmer, 2003).

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) version 2005 (NeuroHealth System, LLC, Pittsburgh, PA) is a computer-based program used to assess neurocognitive function and concussion symptoms (Lovell, Collins, Iverson, Fields, Maroon, 2001). The ImPACT software is described in greater detail in Chapter 3.

Previous research has been done to examine the test-retest reliability and validity of the ImPACT test battery. ImPACT has been designed to minimize practice effects commonly seen with paper and pencil testing (Iverson, Lovell, & Collins, 2003). Assessment of test/retest reliability (Pearson r) was determined on five occasions, two days apart (Lovell et al., 2001). Reliability ranged from .52-.92.

Iverson, Lovell, Collins, and Norwig (2002) also examined the test-retest reliability of test scores by administering the ImPACT examination to 49 non-concussed amateur athletes at least two times with an average retest interval of 14 days between sessions. Researchers found no statistically significant changes or practice effects for memory, reaction time, or processing speed composite scores on the ImPACT examination following the two sessions of test administration. The .80 confidence interval for reliable change was 10 points for the memory, .10 seconds for reaction time, and 8 points for processing speed (Iverson, et al.)

Computerized neuropsychological testing, such as ImPACT, must also be sensitive to the acute effects of concussion. The validity of ImPACT is dependent on whether or not the program can discriminate between a concussed and non-concussed individual.

Another study conducted by Iverson, Lovell, and Collins (2002) examined 120 amateur high school and college athletes three days after sustaining a concussion. The concurrent validity of ImPACT was measured by determining whether or not test scores were sensitive to the acute effects of a concussion. After their post-concussion tests, results showed that subjects scored significantly worse on both reaction time and memory tasks as compared to their baseline.

To examine divergent validity researchers used an intercorrelation matrix of composite scores preseason and post-concussion (Iverson et al., 2002). Preseason baseline results demonstrated significant correlations for reaction time and processing speed. Results revealed significant post-concussion correlations exist between symptom scores and memory(r = -0.38), memory and reaction time (-0.27), memory and processing speed (0.35), and reaction time and processing speed (-0.32) for post-concussion scores. Researchers believe that these small correlations show that scores on the test do not have shared variance therefore are thought to measure different things (Iverson). Iverson et al. concluded through the current study that ImPACT was in fact sensitive the acute effects of concussion in young amateur athletes, supporting the validity of the computerized test battery.

Iverson, Lovell, and Collins (2005) examined the construct validity of the ImPACT test battery by comparing it to the Symbol Digit Modalities Test (SDMT). The Symbol Digit Modalities Test (SDMT) is a traditional paper-and-pencil neuropsychological measure frequently used in sports concussion research (Iverson et al., 2005). Seventy-two amateur athletes participated in this study. All participants were seen within 21 days of sustaining a concussion. Participants were administered both the ImPACT test and Symbol Digit Modalities Test. Results showed there was a positive correlation between the performance on the SDMT and processing speed and reaction time scores on the ImPACT assessment. This study supports ImPACT's sensitivity on deficits to cognitive function following concussion.

Most recently, Schatz et al. (2006) examined the sensitively and specificity of the ImPACT test on individuals diagnosed with a concussion. Seventy-two high school athletes who sustained a concussion were ImPACT tested within 72 hours of the initial injury. Their scores were then compared to 66 high school athletes with no history of concussion. Between-group comparisons showed a significant multivariate effect of concussion on test performance. Analysis of the battery scores showed an 81.9% sensitivity and 89.4% specificity for the assessment of neurocognitive and neurobehavioral sequelae (Schatz et al.). In addition, discriminant analysis correctly classified 82% of the concussion group and 89% in the control group.

These studies demonstrated that ImPACT can help provide post-concussion data which can assist the sports medicine team in making decisions on return-to-play (Schatz et al, 2006). However, more research needs to be done to further determine the reliability, validity and presence of practice effects in this computerized neuropsychological test battery.

Cognitive Function and Exercise

It has been reported that between 1930 and 1999, over 200 studies have examined the effects of exercise on cognitive function (Brisswalter, Collardeau, & Rene, 2002). Despite the plethora of research, results continue to be inconclusive and at times contradictory. Results of some studies show a beneficial or a facilitating effect of exercise on cognitive function, while others show exercise to be detrimental and debilitating to certain mental tasks (Hogervost, Riedel, Jeukendrup, & Jolles, 1996; Paas & Adam, 1991; Fleury & Bard, 1987; Hancock & McNaughton, 1986; Salmela & Ndoye, 1986; McGlynn, Laughlin, & Bender, 1977; Levitt & Gutin, 1971; Gutin & DiGennaro, 1968b). Results of these studies are difficult to compare due to varying exercise durations, intensities, subject fitness level, and a variety of cognitive tests administered.

Intense Exercise and Cognitive Function

It has been a common assumption among members of the research community that intense exercise will cause exhaustion and therefore lead to a decreased performance on cognitive tasks (Tomporowski, 2003). To examine intense exercise and its effect on cognitive function, researchers select tasks that often involve anaerobic activities, which require increased levels of muscular power, resulting in subjects reporting a fatigue state. To date, no studies have determined a definitive relationship between cognitive performance following an intense bout of exercise. (Tomporowski, 2003).

Results of previous research comparing the performance on cognitive tasks following a short-intense bout of exercise have been inconsistent and contradictory (Bard & Fleury, 1978; Gutin & DiGennaro, 1968a; Hancock & McNaughton, 1986). Previous studies have supported both impairment and facilitation of cognitive tasks following intense bouts of exercise (Bard & Fleury, 1978; Gutin & DiGennaro, 1968a; Hancock & McNaughton, 1986).

An early study conducted by Gutin and DiGennaro (1968a) showed no impairment in a simple addition task following a 12-minute run to exhaustion. Bard and Fleury (1978) studied 16 male subjects and their performance on three visual cognitive tasks following a cycling protocol to exhaustion. They examined letter detection, spatial location, and timing during the cycling protocol. Results revealed no effect of the short-intense bout of exercise for all three cognitive tasks.

Similarly, Fleury, Bard, Jobin, and Carriere (1981) were unable to demonstrate that exercise affected the results of cognitive performance in 31 male subjects. The research has examined the effects of visual perception on three different treadmill protocols. All three protocols were designed to fatigue the subject. One protocol involved a short anaerobic lactic acid effort while recruiting phosphocreatine. The second protocol involved supramaximal effort with the recruitment of glycogen stores. The third protocol was a partial anaerobic workout with the recruitment of glycogen and oxygen. Results revealed that none of the three treadmill protocols affected the letter detection task.

In 1986, Hancock and McNaughton examined short-term memory, time estimation, and symbol interpretation during a treadmill run to anaerobic threshold. Subjects were six experienced orienteers. Results of this study demonstrated facilitation on short-term memory and time estimation, but impairment on symbol interpretation. Investigators concluded that exercise may affect different levels of cognitive processing in varying ways.

Studies conducted by Wrisberg and Herbert (1976) and Issacs and Pohlman (1991) both reported impairments on coincidence timing task following a treadmill run to exhaustion. Issacs and Pohlman fatigued their subjects by using a progressive cycling protocol to 100% VO_2 max, whereas Wrisberg and Herbert used a treadmill run to exhaustion.

Only one study to date has investigated the effects of exertion on a concussion grading system. Leclerc, Hussain, and Johnston (2002) studied the effects of a 4-minute treadmill run at 80% of a subjects age predicted maximal heart rate and performance on the McGill Abbreviated Concussion Evaluation (McGill ACE). Football and ice hockey collegiate athletes completed the McGill ACE and months later were put through an exertion protocol and retested. There were no significant differences on pretest and post test scores. The researchers concluded that the McGill ACE is a valid means of concussion baseline assessment.

Previous research shows that there is little effect on cognitive function following brief, intense exercise. When a change in cognitive function following brief, intense exercise has been seen, Tomporowski (2003) describes these changes as "small and transitory." It is hypothesized that the body recovers from the fatigue state caused by the bout of exercise quickly, which allows for minimal change in neurocognitive function.

Exercise Induced Arousal and Cognitive Function

Improvements in cognitive performance following exercise are often described as resulting from an increase in arousal. Increases in arousal facilitates and promotes central nervous system function which including increasing catecholamine levels, cortical blood flow, and the body's core temperature (Tomporowski, 2003). Improved cognitive states and performance are believed to result from the neurophysiological changes caused by arousal.

Most studies that have shown facilitation of cognitive performance following exercise have used protocols involving both aerobic and anaerobic exercise that lasts less than 20 minutes (Tomporowski, 2003).

Davey (1973) studied the effect of exercise on short-term memory. Twenty male college students were asked to cycle against resistance for varying periods of time ranging from 15 seconds to 10 minutes. Subjects were then tested for mental performance at varying levels of exertion. Results of the study showed that at a submaximal level no impairment of memory was observed. As intensity and length of exertion increased over time, there was a decrease in mental performance.

Sjoberg, Ohlsson, and Dornic (1975) examined the effects of cycling exercise at different percentages of VO_2 max on short-term memory. Participants in this study had to cycle at 0%, 25%, 50%, and 75% of VO_2 max. Results revealed that there was facilitation of the short-term memory cognitive task when cycling at 75% of VO_2 max. However, this study did not support the inverted-U hypothesis.

Allard, Brawley, Deakin, and Elliot (1989) completed a series of studies examining the effect of visual search and letter matching during a cycling protocol at different levels of VO_2 max. The first part of the experiment had participants cycling at 0%, 30%, and 60% of their VO_2 max. During the cycling protocol subjects were asked to perform a visual search task. As workload increased, there was improvement in visual search performance. The second part of this study examined subject's letter matching while cycling at 30% and 70% of VO_2 max. Subjects had to decide whether or not letters had the same appearance. There was no improvement with letter matching during exercise.

A study conducted by McMorris and Graydon (1997b) examined the effects of exercise on sport specific soccer tasks. In the first experiment, 12 collegiate soccer players were asked to detect the presence of a ball on slides in both game and non-game contexts. Subjects were tested at rest, 70%, and 100% of their maximal power output on a cycle ergometer. Results of experiment showed significantly faster visual search times at 100% maximal power output than the other two conditions. In the second experiment twelve collegiate soccer players were presented with soccer situations, similar to the slides during the first experiment. Subjects were asked to determine what decision the player should perform with the ball. Subjects selected either run, dribble, or shoot. Subject's responses were compared to the responses of a soccer coach's panel. Similarly to experiment one, subjects were tested at rest, 70%, and 100% of maximal power output. Results indicated that total speed and accuracy of the decision were significantly quicker at maximal exertion.

Arcelin, Brisswalter, and Delignieres (1997) investigated 22 subjects and their performance on a discrimination task during a bout of cycling exercise at 0% and 60% of VO_2 max. The cognitive task was performed at three minutes and then at eight minutes into the cycling exercise. Results showed improvement on the cognitive task at the end of the exercise period compared to the beginning.

In 1998, Aks studied the effect of cycling exercise on visual search following low-level aerobic exercise and high-level anaerobic exercise. Ten women and ten men performed ten minutes of low-level activity. Subjects performed a visual search after completing the low-level activity. Subjects then performed ten minutes of cycling at a high level of anaerobic exertion, which was then following by the visual search task. Participants improved their speed and accuracy on the visual search task following both exercise protocols. The researchers concluded performance was most improved following the high level bout of anaerobic exercise.

In 1980, a study by Sjoberg (1980) examined the effects of cycling at different levels of VO_2 max and its effect on short-term memory. Results of the study revealed no effect of the cycling exercise on short-term memory. Results did appear to support fitness level may have affected cognitive performance. In another study by Sjoberg (1980) subjects with an average fitness level performed significantly better than participants with a lower level of fitness. In both the previous studies, results support that individuals with a higher level of fitness or previous exposure to a task may be able to counterbalance the effects of strenuous exercise.

A study by Delignieres, Brisswalter, and Legros (1995) showed improvements in performance based upon their experience in fencing. The study compared the reaction time between experienced fencers and individuals who were equally physically fit, but did not have the same exposure to rapid decision making as in the sport of fencing. The researchers selected fencers because the nature of fencing forces participants to make rapid decisions. Participants in this study were asked to perform both a two-choice and four-choice reaction test during the last minute of a four-minute exercise protocol. The exercise protocol consisted of a bout of cycling at 20%, 40%, 60%, and 80% of the subjects VO_2 max. Results reveal that fencers performed significantly faster on reaction time compared to those with no fencing background. Increased performance in the reaction time tasks were seen at the 40%, 60%, and 80% workload. The researchers concluded that those individuals with previous experience at a task and rapid decision making, may aid with performance in a cognitive task following a bout of exercise.

Many factors determine an individual's performance on a cognitive task following a short bout of aerobic or anaerobic exercise. An individual's level of arousal, previous experience, and fitness level may factor in cognitive performance during short bouts of exercise. However, more research is needed on exercise-induced arousal, and the inverted-u hypothesis and how it relates to performance on cognitive tasks.

Aerobic Exercise and Cognitive Function

As previously mentioned, exercise has been known to improve a person's mood and increase overall mental processes (Tomporowski & Ellis, 1986). Steady-state aerobic exercises, similar to bouts of brief intense anaerobic exercise, have been used in previous research to create fatigue states in participants. However there are discrepancies in the literature concerning the effects of steady-state aerobic exercise on cognitive function. Some studies in this area have shown improvements in decision making tasks, simple reaction time, and response control, whereas others have shown either no effect or impairment in an individuals performance on cognitive tasks (Fleury & Bard, 1987; Gondola, 1987; Hogervorst et al., 1996; Paas & Adam, 1991; Tomporowski, Ellis, & Stephens, 1987). Tomporowski (1997) reports that aerobic exercise performed between 20-60 minutes facilitates many facets of cognitive function. For example, following aerobic exercise, individuals often concentrate and are able to solve complex problems more effectively than pre-exercise (Tomporowski). Research that has involved steady-state aerobic exercise involved sub-maximal effort lasting for longer than 30 minutes (Tomporowski, 2003).

Research by Gondola (1987) examined a bout of aerobic exercise on women's higher order thinking. A sample of 21 young women were administered three tests involving thinking and problem solving skills following a 20 minute dance class. Sixteen young women who did not participate in a dance class served as a control in this study. Results showed that women who participated in the exercise class did better on the thinking and problem solving tasks than those who did not exercise. Gondola concluded that aerobic exercise may be beneficial to subject's cognitive function.

Paas and Adam (1991) examined both decision-making and perception in sixteen individuals following three different cycling protocols (endurance, interval, minimal load) and at rest. During the decision task, subjects had to identify three letters. For the perceptual component, subjects had to look at a row of numbers and determine which number was larger than the rest. After the 40-minute endurance cycling task, results showed facilitation of both the decision-making and perception task. There were no differences in the performance of the cognitive tasks following the interval cycling, minimal load, or rest protocols.

Hogervorst et al. (1996) showed significant improvements in simple reaction time following a bout of moderate exercise. Subjects in this study were 15 trained tri-athletes and competitive cyclists. Subjects were asked to complete a series of cognitive task before and following a 60-minute cycling time trial at 75-85% of their VO_2 max. Three reaction time tests measuring both simple and choice reaction time were utilized for this study. A finger tapping test and abridged version of the Stroop-Color Word test was also administered. Results of this study showed a positive effect of exercise on simple reaction time. There was no improvement with choice reaction or the finger-tapping test. Completion time of the Stroop-Color Word test decreased following exercise.

Tomporowski et al. (1987) studied participant's free-recall memory following a 50-minute treadmill run. Both a control and experimental group were used in this study. Results showed that there was no effect on free-recall memory when comparing the group that performed exertional aerobic activity and the control group. It was concluded that the exercise intervention had no effect on an individual's ability to remember previously presented information.

Cian, Koulman, Barraud, Raphel, Jimenez, and Melin, (2000) examined aspects of cognitive function in eight healthy men following four separate experimental conditions. Three were based on hydration which included: 1) euhydration, 2) hyperhydration, and 3) dehydration by heat chamber. The fourth experimental condition was a treadmill exercise protocol at 60% of the individuals VO_2 Max until there was a 2.8% weight loss. Subjects achieved their weight loss in approximately two hours. Participants were asked to complete five cognitive tests before and 30 minutes after each experimental condition. These tests included (1) memory-recall using photographs, (2) four-choice serial reaction time test, (3) a perceptive discrimination task, (4) the Digit Span for short-term memory, 5) and tracking. Results of this study show that following exercise there was no effect on reaction time or the recall memory. Significant impairment was demonstrated on tracking exercise, Digit Span for short-term memory, and perceptual discrimination task. Following a session of rehydration, no effect was seen on the choice reaction time, perceptual discrimination, and short-term memory. Performance on both long-term recall memory and tracking exercise showed significant impairments following hydration. A similar study was conducted by Cian, Barraud, Melin, and Raphel (2001). In this study seven subjects underwent a treadmill run at 65% of their VO_2 max until 2.8% of their body weight was lost (mean = 2hr). Following a 30 minute recovery, subjects were administered a battery of five tests. There were no significant differences on choice reaction time, tracking or long-term recall memory. Subjects exhibited significant impairment on both perceptual discrimination and short-term memory. Following a one-hour recovery/hydration period no effects were seen in reaction time, tracking and long-term recall memory. Perceptual discrimination was still impaired. Short-term memory was improved following hydration. The two previously mentioned studies provide insight into the effects of steady-state aerobic exercise and hydration on cognitive function.

The previously mentioned studies all attempt to determine a relationship between steady-state aerobic exercise and cognitive function. Studies of this nature are difficult to compare due to the variety of cognitive tests and exercise protocols used. It should also be mentioned that outside factors such as previous exposure to a task, expertise, fitness level, or hydration may play a role in the performance of cognitive task following exercise. More research needs to be done in order to better understand the effects of exercise on cognitive function.

Gender and Cognitive Performance

Gender differences in cognitive performance have been reported for verbal memory, perceptual motor speed, and visualspatial tasks (Kimura & Clark, 2002; Lewis and Kamptner, 1987). Weiss, Kemmler, Deisenhammer et al. (2003) found that females perform better on verbal memory and perceptual motor speed compared to males. Conversely, males perform better on visuospatial tests than females. Similarly, Barr (2003) reported female athletes performed better on verbal initiation compared to male athletes. Females may perform better on baseline verbal memory scores due to increased levels of estrogen compared to males. Maki, Zonderman, and Resnik (2001) reported females who received hormone replacement therapy exhibit better verbal memory test scores than women who did not receive hormone replacement therapy. Because womens' sports participation has expanded significantly during the past decade and brain function differs between genders, it is important to determine if collegiate male and female recreational athletes exhibit differences on neuropsychological function after an intense bout of exercise.

Review of Maximal Oxygen Uptake

Maximal oxygen uptake, or VO_2 max, can be defined as the highest rate at which oxygen can be taken up and used by the body during exercise (Bassett & Howley, 2000). Maximal oxygen uptake is a commonly used measure amongst exercise physiologists, and is often used to determine cardiorespiratory fitness and exercise prescription. Originally described in the 1920's, Hill and Lupton (1923) hypothesized that there was an upper limit to the amount of oxygen a person can consume. Their original paradigm also explains interindividual differences in VO_2 max, believing that there was no universal VO_2 max. Hill and Lupton also hypothesized that higher levels of VO_2 max are a precursor for achievement in middle and long distance runners. The researchers concluded that an individual's maximal oxygen uptake is limited by the ability of the cardiorespiratory system to transport oxygen to the muscles of the body.

Since the early research by Hill and Lupton (1923), it is widely believed by those in the field of exercise physiology that there is a physiological limit to the amount of oxygen the body can consume (Bassett & Howley, 2000). Many protocols exist that try to accurately measure maximal oxygen consumptions. Graded exercise tests are a common method in assessing an individuals VO_2 max. It is generally accepted by researchers that to achieve the highest oxygen consumptions values, VO_2 max, should be conducted on a treadmill (Warpeha, 2003). Oxygen uptake is measured through gas exchange and graphed against the intensity of the work. A plateau represented by the graph signifies when an individual has achieved their maximal oxygen uptake.

Research has shown that only 50% of individuals demonstrate a plateau when they are stressed to maximal effort (Howley et al., 1995). It is for this reason that a graphical plateau should not be the only item used to determine when an individual has reached VO_2 max. In order to verify an individual reaching a true VO_2 max, additional measurements should be taken into consideration. An individual should have a respiratory exchange ratio >1.15 (Issekutz, Birkhead, & Rodahl, 1962) and a blood lactic acid level of >8-9 mM (Astrand, 1952).

Bassett and Howley (2000) present four main factors that may limit an individual's maximal oxygen uptake. They include the pulmonary diffusing capacity, cardiac output, the oxygen carrying capacity of the blood, and skeletal muscle characteristics. Pulmonary diffusing capacity is the ability of the lungs to provide oxygen to the arterial blood. Limitations in pulmonary function are apparent in individuals performing exercise at higher altitudes, individuals with asthma, obstructive pulmonary diseases, and untrained athletes (Faulkner, Kollias, Favour, Buskirk, & Balke, 1968). Trained and elite athletes have a more efficient pulmonary system and higher cardiac output leading to higher levels of oxygen uptake (Dempsey, Hanson, & Henderson, 1984).

Cerretelli and DiPrampero (1987) estimate that 70-80% of the limitation in an individual's VO_2 max is due to maximal cardiac output. The idea of maximal cardiac output being a limiting factor in an individuals VO_2 max was originally developed by Hill et al. in the early 1920's (Hill, Long & Lupton, 1924; Hill & Lupton, 1923). By training, an individual increases blood flow to the body, thus increasing oxygen delivery to muscles and subsequently their VO_2 max (Saltin, 1985; Ekblom, Astrand, Saltin, Stenberg, & Wallstrom, 1968).

It was previously mentioned that the oxygen carrying capacity is a factor limiting VO_2 max. Blood doping has become a common practice in efforts to increase the body's ability to transport blood and oxygen to skeletal muscles. This process, which is outlawed by the National Collegiate Athletic Association, the International Olympic Committee, and most professional sports leagues, involves removing, storing, and reinfusing an individuals blood. Blood doping has shown to increase the body's oxygen carrying capacity and has been shown to increased VO_2 max by 4-9% (Gledhill, 1982).

Bassett and Howley (2000) suggest that skeletal muscle may play a role in the limitation of VO_2 max. Current research has focused on muscle mitochondria versus contractile properties and the interaction with oxygen transport. However, more research is needed to determine the relationship between VO_2 max and skeletal muscle. It is concluded that there is no single limiting factor of VO_2 max. It is a culmination of many factors along every step throughout the oxygen transport process. Thus, intrinsic and extrinsic factors such as altitude, anemia, and a decrease in cardiac output may also lead to reduction of an individual's VO_2 max (Wagner, Hoppeler, & Saltin 1991).

VO_2 max is not thought to be the "best predictor of athletic ability," but instead is seen as an "upper limitation for energy production for performance in endurance events" (Bassett & Howley, 1997; Noakes, 1998). Trained individuals have been shown to have an enhanced running economy and are able to maintain higher percentages of VO_2 max during exercise (Bassett & Howley, 2000).

Since being discovered in the 1920's there have been significant contributions to the understanding of VO_2 max, and its limiting factors. Researchers are in agreement that future studies need to be conducted in order to better understand one of exercise physiology's most fundamental methods.

Concussion - Background

The word concussion is derived from the Latin verb *concussus* which means to shake violently (Cantu, 2001). Recently the definition of a concussion has been the subject of much debate. In 1966, the Committee on Head Injury Nomenclature met and defined a concussion as a "clinical syndrome characterized by immediate and transient impairment of neural function, such as an alteration of consciousness, disturbance of vision and equilibrium due to brain stem involvement" (Congress of Neurological Surgeons, 1966). In 1996, the Traumatic Brain Injury Act of 1996 introduced the term *traumatic brain* injury (TBI). Since the introduction of that term, the term cerebral concussion has been interchangeably used with mild traumatic brain injury (MTBI) (Maroon, Lovell, Norwig, Podell, Powell, Hartl, 2000). Athletes that suffer a concussion or MTBI often experience a myriad of symptoms including loss of consciousness, headache, confusion, balance disturbance, blurred vision, and amnesia (Oliaro, Anderson, & Hooker, 2001).

The effects of concussion are cumulative. If an athlete is still experiencing symptoms that result from a concussion and then returns to play prematurely, this may potentially lead to catastrophic consequences (Cantu & Voy, 1995; McCrory & Berkovic, 1998). For this reason, numerous grading scales and guidelines were developed in attempts to classify and determine severity of concussion. The three most commonly used are the Colorado Medical Society, the Cantu Grading System, and the grading scale developed by the American Academy of Neurology (Bailes & Cantu, 2001). Discussing these three grading scales individually is beyond the scope of this literature review. In most scales developed, researchers have used loss of consciousness and posttraumatic amnesia as the focal point in the grading scales (Bailes & Cantu, 2001).

Similar to the disagreements of determining severity of injury, there is little conformity on the return-to-play criteria. Despite more than a dozen guidelines developed for return-to-play, the only consensus among clinicians and researchers is that the athletes should be symptom free at rest and with exertion before returning to participation (Wojtys, Hovda, Landry, Boland, Lovell, & McCrea, 1999;

Bailes & Cantu, 2001; Guskiewicz, Bruce, Cantu, Ferrara, Kelly, McCrea et al., 2004; Randolph, McCrea, Barr, 2005). Cantu (1988) states that return to play should be based on clinical judgments and be handled individually on a case-by-case basis. Furthermore, decisions on return-to-play should be based on a thorough clinical assessment, involving postural-stability testing, diagnostic imaging, and neuropsychological testing (Bailes & Cantu, 2001; Guskiewicz, et al.)

CHAPTER 3

METHODS

The primary purpose of the study was to examine the effects of an exhaustive bout of exercise to VO_2 max on verbal and visual memory, motor processing speed, reaction time, and impulse control. A secondary purpose of this study was to examine gender differences in cognitive function following a bout of exhaustive exercise.

Research Design

A three factor (exercise, gender, time) repeated measures design was used for this study with time as the within-subjects factor and gender and exercise as the between-subject variables. The dependent variable was cognitive function which was divided into verbal and visual memory composite scores, motor processing speed, reaction time, and impulse control. The intervention used for this study was an exhaustive bout of exercise to VO_2 max.

Participants

One hundred and seven recreational athletes from a Large Midwestern University (n=107) volunteered to participate in the study. Bing et al. (2004) defines a recreational athlete as someone who participates in sport or physical activity 2-3 times per week. Participants were between the ages of 18-24 years old and reported no lower extremity injury or concussion within the past 12 months. Participants with history of self-reported cardiovascular or respiratory illness were excluded from the study. Volunteers who reported colorblindness were also excluded.

Instrumentation

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) version 2005 (NeuroHealth System, LLC, Pittsburgh, PA) is a computer-based program used to assess neurocognitive function and concussion symptoms (Lovell, Collins, Iverson, Fields, Maroon, 2001). The software program is run from either a desktop PC or laptop using Windows NT operating system or higher (Lovell). The program uses a keyboard and external mouse to allow participants to select responses and navigate through the six test modules.

The ImPACT protocol consists of three categories. The first category includes a demographic information section. The user was asked to navigate through a series of instructional screens where they were asked to enter descriptive information about themselves, such as demographics, years in school, presence of any learning disabilities, or neurological disorders.

The second category consists of 22 concussion symptoms that athlete's rate using a 7-point Likert scale.

Concussion symptoms include headache, nausea, vomiting, balance problems, dizziness, fatigue, trouble falling asleep, sleeping more than usual, sleeping less than usual, drowsiness, sensitivity to light, sensitivity to noise, irritability, sadness, nervousness, feeling more emotional, numbness or tingling, feeling slowed down, feeling mentally foggy, difficulty concentrating, difficulty remembering, and visual problems. Athletes self-rate their concussion symptoms by clicking on a number between 0 (not experiencing) and 6 (severe) using an external mouse.

The third category consists of six neuropsychological test modules. It is important to note that ImPACT has multiple built-in design/word groups. This is important to limit practice effects. A different word/design group was administered to the participant for each test. Module 1 of the neurocognitive test battery focuses on word discrimination. This section is used to evaluate verbal memory and attentional processes. Subjects are presented with 12 words two times each for 750 milliseconds. Individuals are then tested to recall words from a 24-word list. There are 12 target words and 12 non-target words. Using the mouse, subjects are prompted to select "yes" or "no" depending on whether or not the word was presented in the original list. After a 20-minute delay, subjects are asked again to recall this list of words. A total score of percent correct is given at the end of the battery.

Module 2 evaluates attention and visual recognition through design memory. Similar to Module 1, 12 target designs are presented twice for 750 milliseconds. Following the presentation subjects are asked to recall these designs, choosing from the 12 target and 12 non-target designs presented. Subjects are prompted to click "yes" or "no" depending on whether or not the design was originally presented. A total score of percent correct is given at the end of the battery.

Module 3 is designed to measure visual working memory, visual processing speed, and visual memory. This section incorporates a distractor which is a reaction time test that asks the subject to click the left mouse button if a blue square appears, and the right mouse button if a red circle appears. For the memory test, a random assortment of X's and Os are displayed for 1.5 seconds. Of this random assortment, three X's/O's are illuminated in yellow. The subject is instructed to remember the placement of these illuminated objects. Immediately following the presentation of the three illuminated X's/O's, the subject is asked to complete the distractor task. After the completion of the distractor task, the memory screen reappears and the subject is asked to click on the X's and O's that were originally highlighted. Four trials are completed for this section. Scores for this section include percent correct for identification of the X's/O's and also reaction time scores for the distractor task.

Module 4 is a symbol-matching task that evaluates processing speed, learning, and memory. A grid with nine common symbols and accompanying numbers is utilized. The subject is presented with a symbol below the grid, and is asked to click the number of the corresponding design. After 27 trials, the symbols are removed from the grid. The symbols again are presented below the grid, and the subject is asked to recall the correct symbol/number pairing by clicking the appropriate button. Reaction time scores and memory scores are both calculated.

Module 5 measures choice reaction time and impulse control. Subjects are presented with the words red, green and blue each written in their respective color. Subjects are instructed to click the mouse when the word is correctly matches with the color ink. For this section a reaction time score is provided and also a task error score.

The sixth and final module examines working memory and visual motor response speeds. This module is comprised of both a distractor task and memory component. Participants are presented with and asked to remember three letters. Once the letters are removed from the screen, the participant is presented with the distractor task. A 5x5 grid appears on the screen consisting of 25 numbered boxes. The participant is asked to count backwards, clicking on the corresponding numbered box with the mouse. Following the completion of the distractor task, the participant then must input the three letters in the exact order they were previously presented. There are five trials for this test module. Table 1 lists each test name and the neurocognitive domain being measured.

Table 1 The ImPACT Neuropsychological Test Battery

Test Name	Neurocognitive Domain
Word Memory	Verbal cognitive memory (learning and retention)
Design Memory	Spatial recognition (learning and retention)
X's and O's	Visual working memory and cognitive speed
Symbol Match	Memory and visual motor speed
Color Match	Impulse inhibition and visual motor speed
Three Letter Memory	Verbal working memory and cognitive speed
Symptom Scale	Likert-scale of individual self-reported symptoms

(Lovell et al., 2001)

Procedure

Prior to the start of data collection, the University Committee on Research Involving Human Subjects (UCRIHS) at Michigan State University approved the study. All subjects completed a health history questionnaire and signed a consent form.

After completing the health history questionnaire and consent form, participants were asked to take a practice ImPACT test. This practice test was to ensure that participants understood the directions of the test to eliminate potential mistakes on test day. Following the practice ImPACT test, subjects were scheduled for the testing session and follow-up tests. All testing was done in the Athletic Training Research Laboratory or in the Athletic Training Room. Upon reporting to the testing location, participants volunteered for either the control group or experimental group. Participants in both groups were administered a baseline ImPACT test. Participants in the control group were then asked to remain at rest for fifteen minutes. Participants in the experimental group conducted a VO_2 max treadmill test.

The treadmill protocol began at a speed of 2.5 mph at 0.0% incline. The speed of the treadmill was increased .5 mph per minute until 6.0 mph was reached. Once 6.0 mph was achieved the incline of the treadmill was increased 3% per minute until volitional exhaustion occurred.

Maximal oxygen uptake was defined as the highest value for VO_2 during the test. Achievement of VO_2 max was confirmed by a minimum of two of the three following criteria: 1) respiratory exchange ration (RER) > 1.15, 2) > 90% of their age predicted maximal heart, and 3) plateau of VO_2 (Bassett & Howley, 2000). Heart rate was continuously measured using a Polar HR monitor. Gas exchange was continuously monitored throughout the entire test using a

SensorMedics 2900 Metabolic Measurement Cart. This cart was calibrated before each test with gases of known concentration.

Following the completion of the treadmill test, participants were instructed to immediately begin their follow-up ImPACT test. Likewise, 15 minutes after the baseline test, participants in the control group were instructed to begin their follow-up test. Three days later (mean = 3.20 days) all participants returned to take a second post-test.

Data Analysis

Means and standard deviations were calculated for descriptive purposes. The ImPACT test yields individual scores as well as clinical composite scores for verbal memory, visual memory, processing speed, reaction time, and impulse control. Athletes with a greater score on verbal and visual memory, and processing speed indicate a better performance. Verbal and visual memory scores are presented as a percentage of 100 and processing speed as a number composite score. Athletes with a faster score on reaction time indicate a better performance. All reaction time scores are presented in seconds. The impulse control composite score represents total number of errors on X's and O's distractors and color match. This composite score helps to identify those individuals who may have been confused with directions or may have not given their best effort on the assessment (Iverson et al., 2005). Table 2 illustrates how the clinical composite scores are derived from the individual tests.

Table 2 ImPACT Clinical Composite Scores

Composite Scores	Contributing Scores
Verbal Memory	Word Memory (learning/ recall), Symbol match, and Three letter memory score
Visual Memory	Design memory (learning/ recall), X's and O's percentage correct
Reaction Time	X's and O's, Symbol match (for correct responses), Color Match (for correct responses)
Visual Motor Speed	X's and O's (correct distractors), Symbol Match (correct responses), Three Letters (correctly counted)
Impulse Control	X's and O's (incorrect distractors), Color Match (number of errors)

(Iverson, et al., 2001)

A 2 treatment (experimental, control) x 2 sex (male, female) X 3 time (baseline, post-test 1, post-test 2) analysis of variance with repeated measures was conducted to analyze cognitive function. All 5 neuropsychological test scores were analyzed individually using a repeated measure ANOVA. Paired T-Tests were used to determine if practice effect exists with repeated exposure. The level of significance was set at $p = .05$. All analyses were conducted using SPSS version 11.1 for Windows.

Chapter 4

RESULTS

The primary purpose of this study was to determine if an exhaustive bout of exercise to VO_2 max effects neurocognitive function in recreational athletes. A secondary purpose was to examine if gender differences exist in neurocognitive function between male and female recreational athletes following exhaustive exercise. For clarity, the results section is separated into subject demographics, VO_2 max test results, self-reported fatigue scores, and statistical analysis of cognitive function following the treadmill test. Cognitive function following the treadmill test include verbal composite scores, visual composite scores, motor processing speed, reaction time, and impulse control.

Subject Demographics

A total of 107 subjects volunteered to participate in the study. Five subjects were excluded from statistical analysis because they were classified as outliers. Subjects were determined to be an outlier when any composite score in their dataset was plus or minus three standard deviations from the mean (Vincent, 1999).

Four of the five excluded subjects were members of the control group. One subject was excluded because their performance did not fall within three standard deviations from the mean on the motor processing composite score at baseline. Two datasets were excluded for performance on visual memory composite score at post-test 1 and post-test 2, because scores did not fall within three standard deviations from the mean score. The final dataset was excluded for an impulse control composite score at post-test 1 that did not fall within the three standard deviation range.

The one subject excluded from the experimental group was determined to be an outlier because they scored greater than three standard deviations from the mean on the reaction time composite score during the baseline test and the visual memory composite score during post-test 2.

There were 48 subjects in the control group (age = 21.25 ± 1.74 years, 68.41 ± 2.65 inches, 176.96 ± 30.57 lbs.) and 54 in the experimental group (21.00 ± 1.79 years, 67.61 ± 3.09 inches, 155.94 ± 18.34 lbs.)(See Table 3).

Male subjects reported exercising 3.79 days per week with the majority of their activities including running, weight lifting, and organized team intramural activities such as basketball, football, and soccer. Females reported exercising 3.92 days per week with the majority of their activities including aerobic activity, specifically, running, cycling, or elliptical pedaling, and team intramural activities such as basketball and soccer.

Table 3 Subject Demographic Information

	N	Age (years)	Height (in.)	Weight (lbs)
Control				
Male	23			
Mean		21.55	70.69	197.52
SD		±1.87	±2.72	±36.22
Female	25			
Mean		20.94	66.12	156.40
SD		±1.62	±2.57	±24.91
Total	48			
Mean		21.25	68.41	176.96
SD		±1.74	±2.65	±30.57
Experimental				
Male	27			
Mean		20.93	70.44	176.18
SD		±1.87	±3.14	±23.45
Female	27			
Mean		21.07	64.78	135.70
SD		±1.70	±3.04	±13.29
Total	54			
Mean		21.00	67.61	155.94
SD		±1.79	±3.09	±18.34

VO_2 *Max Test Results*

The average VO_2 max for subjects in the experimental group was 50.30 ± 6.45 mL/kg/min. The average respiratory exchange ratio (RER) was 1.16 ± .067 VCO_2/VO_2. The maximal heart rate was 190.78 ± 8.89 beats per minute. (See Table 4)

Table 4 Maximal Oxygen Uptake Criteria

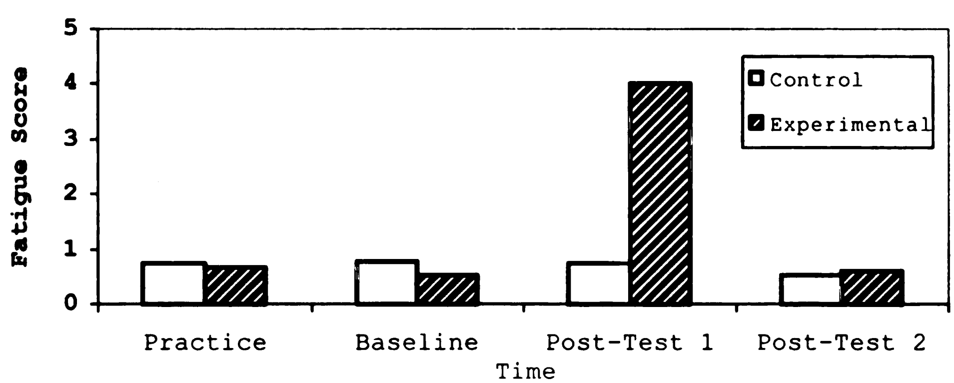
Gender	Maximal Oxygen Output (VO_2 max) (mL/kg/min)	Respiratory Exchange Ratio (VCO_2/ VO_2)	Maximal Heart Rate (bpm)
Females	44.45 ± 5.96	1.12 ± .067	190.95 ± 7.55
Males	56.16 ± 6.93	1.21 ± .067	190.61 ± 10.23
Total	50.30 ± 6.45	1.16 ± .067	190.78 ± 8.89

Self-Reported Fatigue Scores

The second category of the ImPACT neurocognitive software includes a list of 22 post-concussion symptoms. Participants were asked to rate the presence of each symptom on a 7-point Likert scale, ranging from zero (not experiencing this symptom) to six (most severe). For this study only fatigue scores were analyzed.

Two separate 2 gender (male, female) x 4 time (practice, baseline, post-test 1, post-test 2) one-way ANOVAs were conducted to determine differences in self-reported fatigue scores for the experimental and control groups. Results demonstrated significant differences in self-reported fatigue in the experimental group ($F_{(3,52)}$ = 125.77, p = .00) across time (See Table 5). Analysis of the experimental group using pairwise comparison revealed no significant differences between the practice and baseline tests (p = 0.37) or between practice and post-test 2 (p = 0.80) (See Table 6). Significant increases in fatigue scores were demonstrated when the practice test was compared to post-test 1 (p = .00) and when baseline was compared to post-test 1 (p = .00). Significant differences exist between post-test 1 and post-test 2 (p = .00), which illustrate a decrease in the participant's level of fatigue (See Figure 1).

Figure 1 A Comparison of Self-Reported Fatigue Scores



Pairwise comparison for the control group demonstrated no significant differences in self-reported fatigue scores between practice and baseline (p = 0.82), practice and post-test 1 (p = 0.94), baseline and post-test 1 (p = 0.78), post-test 1 and post-test 2 (p = 0.28).

Additional analysis reveal no significant differences in self-reported fatigue scores between males and females in the control group ($F_{(3,46)} = 2.30$, $p = 0.08$), or the experimental group ($F_{(3,52)} = 0.05$, $p = 0.99$) (See Table 7).

Table 5 Individual One-way Repeated Measures ANOVAs Comparing Self-Reported Fatigue Scores for the Experimental and Control Groups

Exercise Group	SS	df	MS	F	p
Experimental	474.24	3	158.08	125.77	.00*
Control	1.68	3	.56	.75	.52

*(significant at the p = .05 level)

Table 6 Individual One-way Repeated Measures ANOVAs Comparing Self-Reported Fatigue Scores Between Exercise/control and Gender

Exercise Group	SS	df	MS	F	p
Experimental x Gender	.19	3	617.30	.05	.99
Control x Gender	5.14	3	1.71	2.30	.08

Gender, Exhaustive Exercise, and Cognitive Function

Statistical analysis revealed no significant differences for the main effect interaction between gender, exhaustive exercise, and time. Therefore for the remainder of this chapter, male and female recreational athletes will be discussed as a single group.

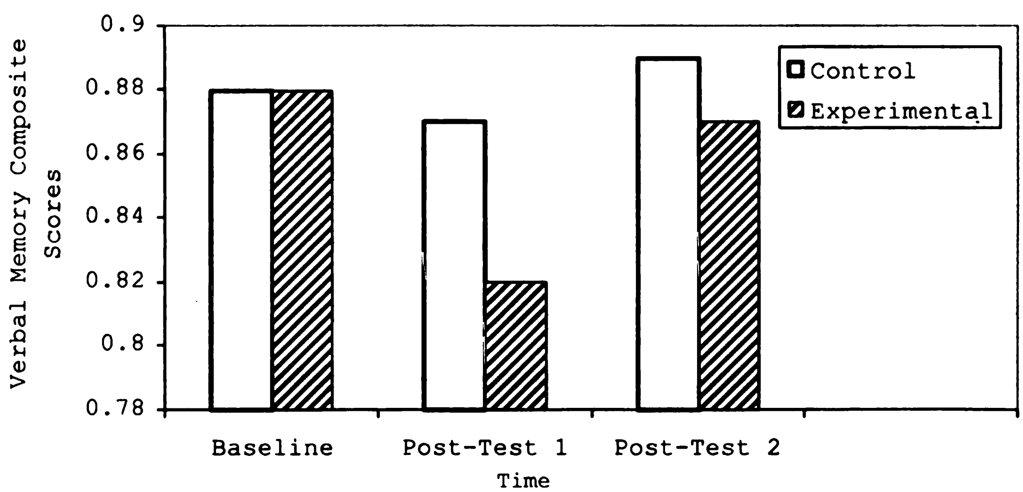
Cognitive Function Following Treadmill Test

The following section will statistically describe the effects of exhaustive exercise on the verbal memory and visual memory composite scores, motor processing speed, reaction time, and the impulse control composite score.

Verbal Memory

A paired-t test was performed to determine practice effects between the practice and baseline tests. Results demonstrated no practice effects for verbal memory composite scores (t = 0.73, p = 0.47, 95% CI = .01 -.02). A 2 gender (male, female) x 2 exercise (control, experimental) x 3 time (baseline, post-test 1, post-test 2) repeated measures ANOVA was conducted to determine differences on verbal memory composite test scores. Results revealed significant differences for the exercise group on verbal memory composite scores ($F_{(2,100)}$ = 3.75, p = .03). Individual one-way repeated measures ANOVA were then conducted to determine significance for the experimental and control groups. Results indicate that significant differences exist among the experimental group ($F_{(2,52)}$ = 14.78, p = .00), but not the control group ($F_{(2,46)}$ = 1.14, p = .33). Further analysis on pairwise comparison revealed significant differences in the experimental group between verbal memory baseline scores and post-test 1 (p = .00), and post-test 1 to post-test 2 (p =.00). Specifically, recreational athletes exhibited impairments immediately after completing a VO_2 max test (See Figure 2). Athletes significantly improved three days following the VO_2 max test on verbal memory composite scores (p = .00). No significance differences exist when verbal memory baseline scores were compared with post-test 2 (p = .23) for the experimental group.

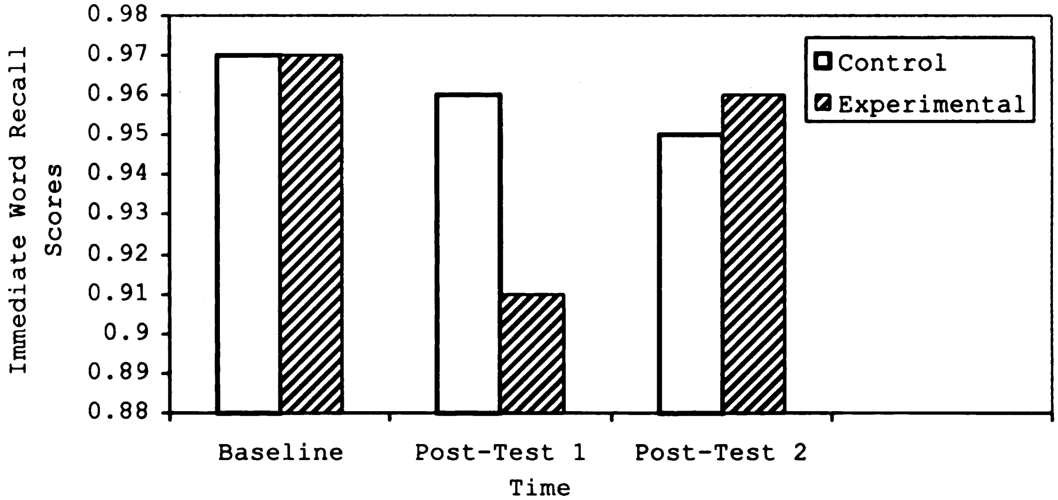
Figure 2 Descriptive Means for the Verbal Memory Composite Scores



Further analysis investigated performance on the individual modules that make up the verbal memory composite score. As previously mentioned the verbal memory score is derived from individual performance on five tasks: 1) immediate recall memory, 2) delayed recall memory, 3) symbol match (with key) 4) symbol match (without key), and 5) 3-letter recall.

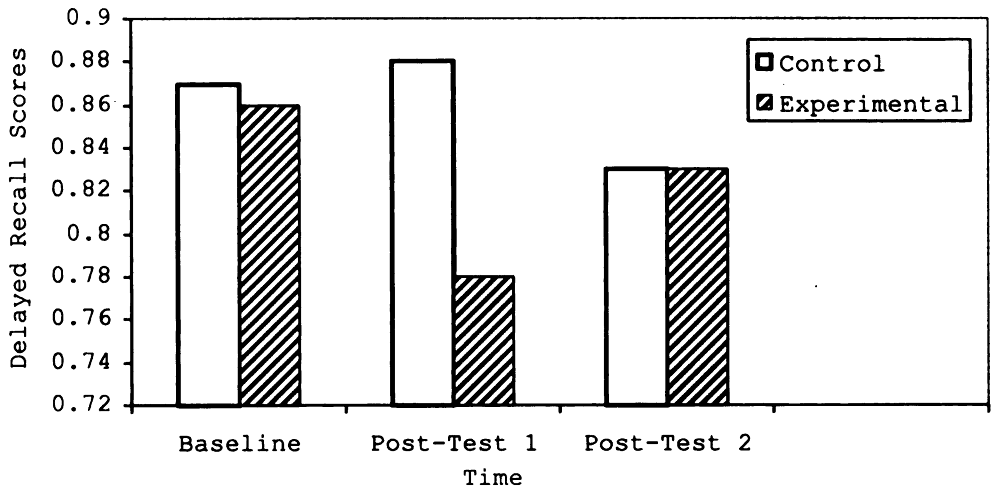
A 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted to determine differences in the immediate memory recall task. Results revealed significant differences for exercise on immediate recall memory scores ($F_{(2,100)} = 7.76$, $p = .00$). Individual one-way repeated measures ANOVA were then conducted to determine significance for the experimental and control groups. Results indicate that significant differences exist among the experimental group ($F_{(2,52)} = 16.45$, $p = .00$), but not the control group ($F_{(2,46)} = 1.80$, $p = .17$). Pairwise comparison demonstrated significant deterioration in scores from baseline to post-test 1 ($p = .00$), and significant improvement from post-test 1 to post-test 2 ($p = .00$). No significant differences were seen in the experimental group between baseline and post-test 2 (See Figure 3)

Figure 3 Descriptive Means for Performance on the Immediate Word Recall Task



A 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted to determine differences in performance on delayed recall word memory. Results revealed significant differences for exercise on delayed recall memory scores ($F_{(2,100)}$ = 5.00, p = .00). Individual one-way repeated measures ANOVAs were conducted to determine differences between the experimental and control groups. Results demonstrated significant differences in both the experimental ($F_{(2,52)}$ = 6.94, p = .00) and control groups ($F_{(2,46)}$ = 4.88, p = .01). Analysis of the experimental group using pairwise comparison revealed significant deterioration in scores from baseline to post-test 1, and significant improvement from post-test 1 to post-test 2. No statistical significance was demonstrated from baseline to post-test 2 (See Figure 4).

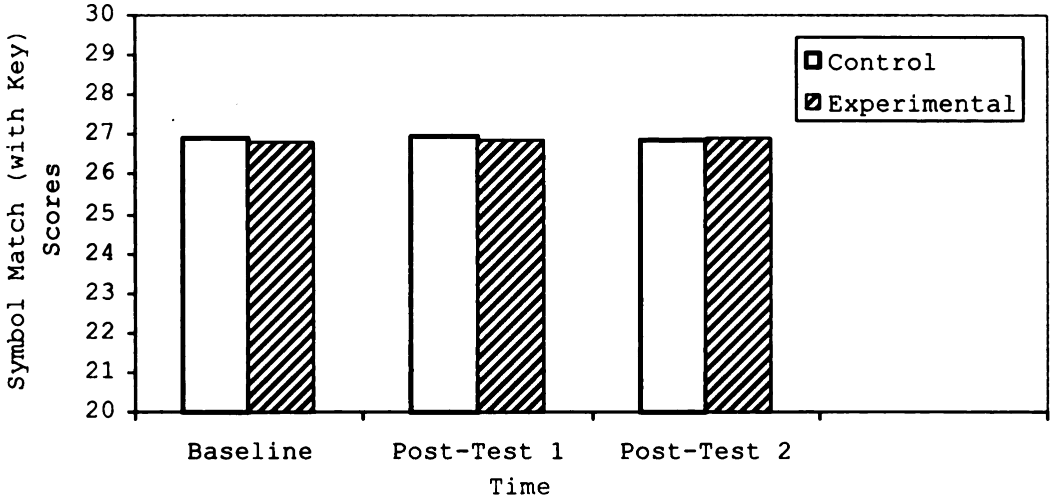
Figure 4 Descriptive Means for Performance on the Delayed Recall Word Memory Task



Pairwise comparisons examining the control group revealed significant deterioration in delayed recall memory scores between post-test 1 and post-test 2, and baseline and post-test 2. No significance was seen between baseline and post-test 1.

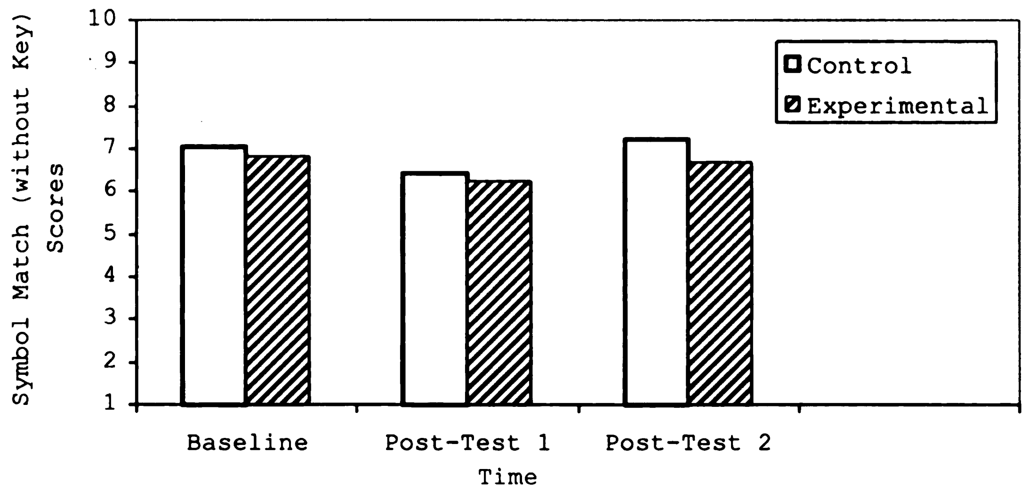
To determine differences in symbol match with key scores a 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted. Results failed to indicate any significant differences for recreational athletes undergoing a VO_2 max test compared to the control group ($F_{(2,100)}$ = 1.16, p = .32) (See Figure 5).

Figure 5 Descriptive Means for Performance on the Symbol Match (with Key) Task



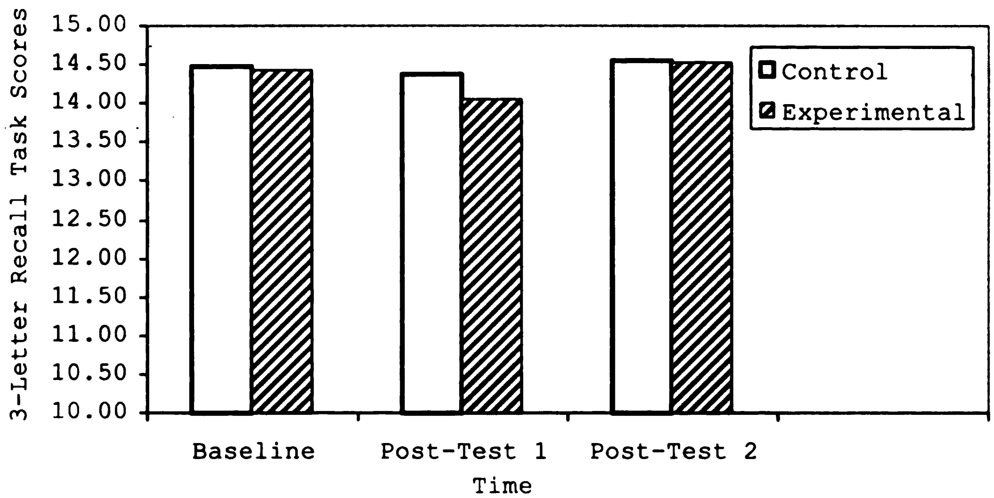
A 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted to determine differences in symbol match without key. Results demonstrated that there were no significant differences between the experimental and control groups ($F_{(2,100)}$ = .52, p = .67) (See Figure 6).

Figure 6 Descriptive Means for Performance on the Symbol Match (without Key) Task



The last component of the verbal memory composite score was the 3-letter recall. A 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted to examine differences in this task. Results revealed no significant differences between the experimental and control groups ($F_{(2,100)}$ = .64, p = .64)(See Figure 7).

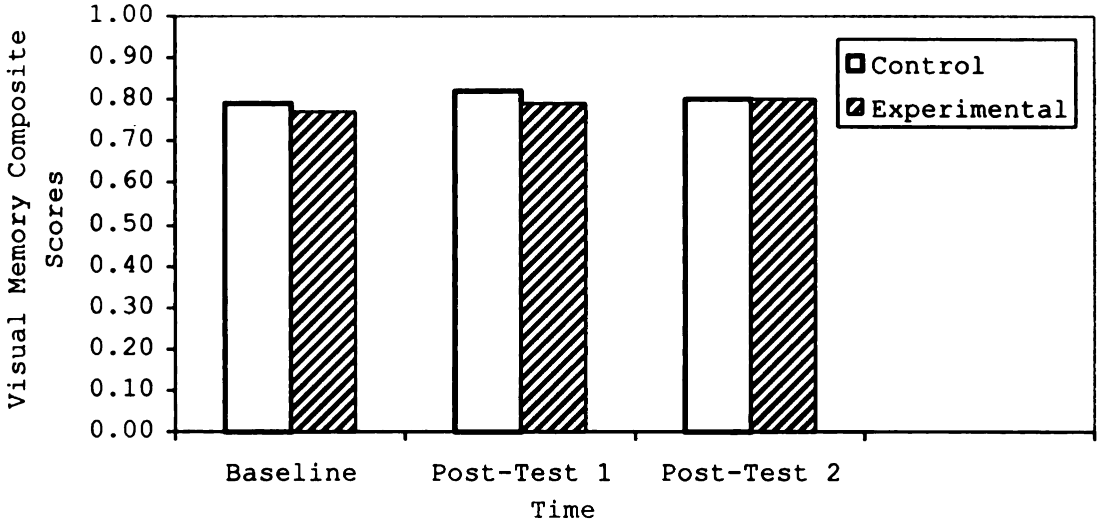
Figure 7 Descriptive Means for Performance on the 3-Letter Recall Task



Visual Memory

A paired t-test was performed to determine practice effects between the practice and baseline tests. Results demonstrated no practice effects for visual memory composite scores ($t = 1.35$, $p = .18$, 95% CI = -.01 - -.04). Therefore, a 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted to determine differences on visual memory composite test scores. Results demonstrated that there were no significant differences between the experimental and control groups ($F_{(2,100)} = .62$, $p = .54$) (See Figure 8).

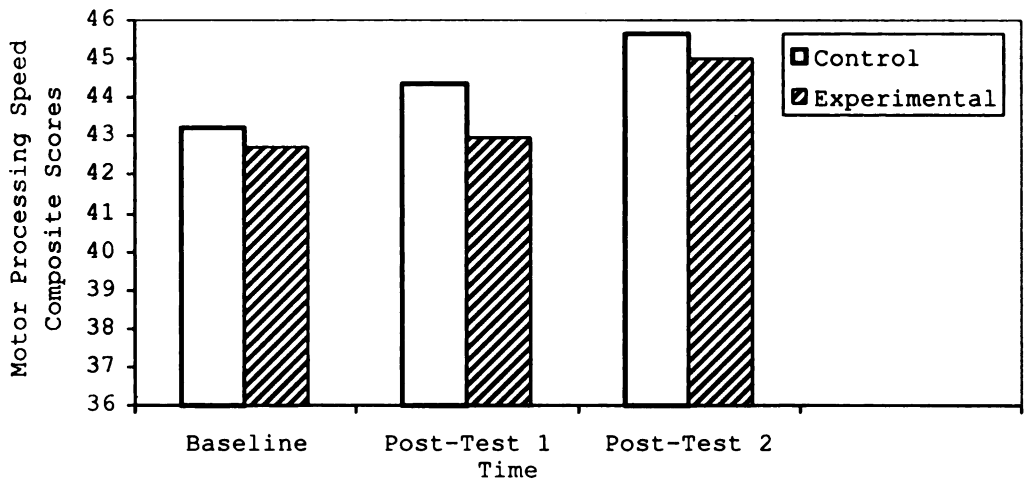
Figure 8 Descriptive Means for the Visual Memory Composite Score



Motor Processing Speed

A paired t-test was performed to determine practice effects between the practice and baseline tests. Results revealed no practice effects for motor processing speed composite scores (t = -.22, p = .83, 95% CI = -1.35 - 1.08). Therefore, to determine differences in composite scores on motor processing speed a 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted. Results failed to indicate significant differences for recreational athletes undergoing a VO_2 max test compared to the control group ($F_{(2,100)}$ = .39, p = .68) (See Figure 9).

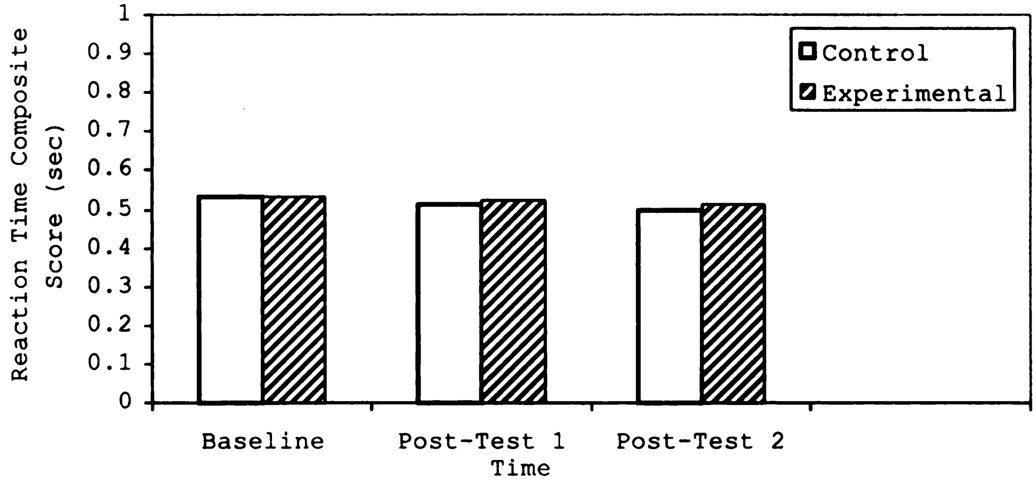
Figure 9 Descriptive Means for the Motor Processing Speed Composite Score



Reaction Time

A paired t-test was performed to determine practice effects between the practice and baseline tests. Results demonstrated no practice effects for reaction time composite scores (t = .22, p = .83, 95% CI = .011 -.014). Therefore, a 2(gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted to determine differences on reaction time composite scores. Results indicated no significant differences exist on reaction time between the experimental and control groups ($F_{(2,100)} = .82$, $p = .44$) (See Figure 10).

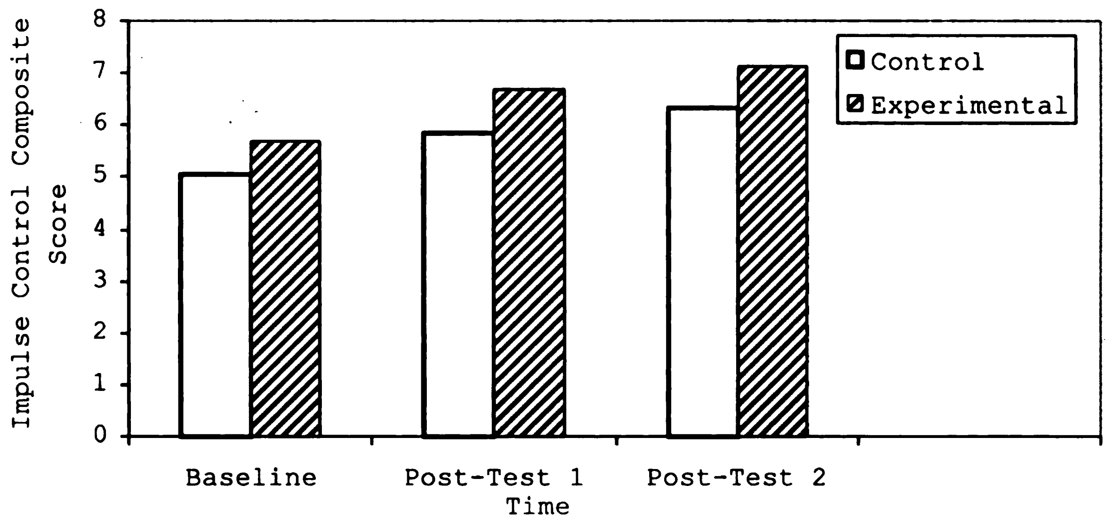
Figure 10 Descriptive Means for the Reaction Time Composite Score



Impulse Control

To determine differences in composite scores on impulse control a 2 (gender) x 2 (exercise) x 3 (time) repeated measures ANOVA was conducted. Results revealed no statistical significance for the experimental and control groups ($F_{(2,100)}$ = .03, p = .97) (See Figure 11).

Figure 11 Descriptive Means for the Impulse Control Composite Score



Research Composite Scores

ImPACT version 2005 has included five new composite scores to assist with clinical research. These composite scores include the immediate memory composite, delayed memory composite, working memory composite, X's and O's memory-speed composite, and the symbol match-memory speed index. These composite scores have yet to be validated by research and are not recommended to make return to sport decisions. For this reason, full statistical analysis was not included in this chapter (See Appendix F).

CHAPTER 5

DISCUSSION

The purpose of this study was twofold. First, to examine the effects of exhaustive exercise to VO_2 max on neurocognitive function. The second was to examine gender differences in neurocognitive function following an exhaustive bout of exercise. This was the first study to demonstrate significant decreases on verbal memory following an exhaustive bout of exercise to VO_2 max.

Gender and the Clinical Composite Scores

Although previous research has demonstrated differences in brain function between males and females, this study revealed no gender differences in recreational athletes on all cognitive function tasks following an exhaustive bout of exercise. Therefore, male and female recreational athletes will be discussed as a single group.

Discussion of the Clinical Composite Scores

The verbal memory composite score was the only clinical composite score that was significantly affected following an exhaustive bout of exercise to VO_2 max. Further analysis which examined the individual test modules that compile the verbal memory composite score revealed significant deterioration on both the immediate and delayed recall tasks following the exercise intervention.

The verbal memory composite score is derived from immediate recall and delay recall memory tasks, a symbol match task and a three letter recall test. Results of the present study are similar to research by Cian et al.(2000) and Frey, Ferry, Vom Hofe, and Rieu (1997) both who demonstrated deterioration on verbal memory tasks after a bout of exercise. Cian et al. attributed the deterioration in performance to dehydration. Additionally, Frey et al. suggested a decrease in performance on memory tasks resulting from changes in cortical activity in the brain and hypoxia brought about by exercise.

It is hypothesized that deterioration on the verbal memory composite scores in this study stemmed from an individual's fatigue following the exhaustive bout of exercise. Subjects in the experimental group, after completing their treadmill test, were immediately administered the follow-up ImPACT assessment. Immediate recall memory was the first task subjects were exposed to on the ImPACT test. It is believed that the anaerobic fatigue state of the subject caused by the treadmill intervention lead to attentional distraction, possibly leading to difficulty remembering the words presented for immediate word recall, and delayed recall at the end of the test battery. The three other components that comprise the verbal memory composite score (symbol match with and without key and the 3-letter recall task) were not significantly effected. It is believed because these modules were presented later in the test; subjects had sufficient time to recover from their fatigue state caused by the exhaustive bout of exercise.

Dehydration may have played a role in the deterioration of the verbal memory composite score. A true causal relationship can not be determined because the current study did not monitor or measure hydration status.

It is possible that motivational factors can also be attributed to the decrease in performance on verbal memory tasks. Subjects in the experimental group, following the intervention were in a fatigued state. This fatigue may have led to decreased motivation to do their best on the post-exercise ImPACT assessment.

There were no significant changes in visual memory, motor processing speed, reaction time, and impulse control composite scores following the exhaustive bout of exercise to VO_2 max. Previous research has demonstrated improvement on visual memory performance tasks. Improvements in this cognitive domain have been attributed to facilitation of the neuromuscular system and increased efficiency of the brain to process components of the visual field as a result of exercise (Hancock & McNaughton, 1986; Allard, et al., 1989).

Previous research that has examined the effects of exercise on reaction time has demonstrated facilitation (Gutin, 1971; Brisswalter, et al., 1995; Hogervost, et al., 1996), deterioration (Brisswalter et al., 1997; McMorris and Keen, 1994) and no effect (Meyers, Zimmerli, Farr, and Bashnagel, 1969; Tsorbatzoudis, Barkoukis, Danis, and Grouios, 1998). Improvement in simple reaction time has been attributed to increases in arousal and activation of the central nervous system caused by exercise. Researchers attribute the deterioration in reaction time performance due to decreases in attention caused by dual task and fatigue from exercise.

Research that demonstrated no effect on reaction time attribute results to the psychometric properties of the instrumentation used, specifically poor reliability and the potential of practice effect.

Finally, there was no significant difference on the motor processing speed composite score following treadmill exercise. Adam, Teeken, Ypelaar, Frans, Verstappen and Paas (1997) and Paas and Adam (1991) demonstrate improvement on information processing tasks following exercise citing increases in arousal and activiation of the central nervous system as reason for this improvement.

Ambiguity and conflicting results in previous research reflect the lack of consistency in methodology, specifically exercise intervention and cognitive assessment instrumentation.

Utilization and Clinical Interpretation of Results

Over the past two decades, understanding the cognitive effects of a concussion, and neuropsychological testing timeline has become an interest of both researchers and clinicians in the sports medicine field (Collins, et al., 1999; Schatz & Zillmer, 2003). Sports medicine professionals in the past have relied on self-reported symptoms and clinical judgements. Currently, computerized neuropsychological testing is being used as a means of quantifying post-concussive symptoms and cognitive deficits in athletes (Collins et al.). Recently, it is becoming common practice in athletic training to administer pre-season baseline tests. Despite the growing interest in neuropsychological testing and the increased clinical utilization, no pre-season baseline schedule currently exists (Schatz & Zillmer, 2003).

Currently, some sports medicine professionals administer a baseline and follow-up neuropsychological test after practice, competition or, immediately following a concussion, while athletes are still in an exerted state. Physical exertion may potentially increase or decrease cognitive function. This is the first study that has investigated the effects of an exhaustive bout of exercise on a specialized computerized neuropsychological test battery such as ImPACT.

Results from this study indicate deterioration in verbal memory following an exhaustive bout of treadmill exercise to VO_2 max. Even with results of the present study, there is not enough research on computerized neuropsychological testing, or the effects of exercise on the ImPACT neuropsychological test battery to make a definitive decision on a timeline for baseline and post-concussion assessment. It is recommended that a baseline or post-concussion ImPACT test not be administered to an athlete immediately following practice, competition, or removal from play due to a concussion. The athlete should be allowed sufficient time to recover and hydrate before being administered the ImPACT test.

Limitations

Variables such as participant's education level, hydration status, and hours of sleep were not controlled in this study. Additionally, only recreational athletes from one Division I-A Institution participated in this study. Recruiting individuals from many institutions and from multiple regions of the country would assist with providing a more diverse sample.

Participant fitness levels were not controlled in this study. This limitation should only have a small effect into the results of this study because the purpose was not to determine a relationship between fitness level and neurocognitive performance. Additionally, there was a 20lbs average weight difference between the experimental and control group. This should not diminish the validity of this study because weight is not a determinant in the ability of an individual's cognitive function or VO_2 max.

Another limitation was participants selected to be a part of either the control or experimental group; there was no random assignment in this study. Random assignment to experimental groups can help improve internal validity and equivalency at the start.

A final limitation to this study was that all six ImPACT test modules were presented in the same order for each assessment. Despite this limitation, ImPACT is programmed to limit practice effects utilizing multiple randomized test forms, including different target word lists for each assessment.

These limitations should be addressed and controlled in future studies that examine the effects of exhaustive exercise on the ImPACT neuropsychological test battery.

Future Research Considerations

Future research should continue to examine the psychometric properties of the ImPACT computerized software. Research on the reliability and validity of the program should investigate practice effects following repeated exposures, and sensitivity to the symptoms and cognitive deficits following a concussion.

Additionally, the effects of exertion on cognitive function can continue to be examined by employing protocols directly related to sport-specific activity. Exercise protocols may include basketball conditioning activity, anaerobic activity that mimics a football drive, or skating drills in ice hockey.

Other areas of future interest should also include recovery following exercise and hydration status and how they affect neurocognitve function. Understanding these two areas will assist clinicians with developing timelines for baseline and post-concussion assessment. The current study can be expanded by including an additional post-test one hour after treadmill activity. This will eliminate the anaerobic effects following the VO_2 max protocol. Hydration status can be monitored and maintained to eliminate it as a confounding variable.

Conclusion

This study examined the effects of VO_2 max treadmill exercise on neurocognitive function, in attempts to assist sports medicine professionals with developing a timeline for baseline and post-concussion ImPACT testing. This was the first study to demonstrate impairment on the verbal memory composite score following a VO_2 max treadmill test. Additional impairments were seen in the immediate memory and delayed memory composite scores.

At the present time there is not enough information to develop a definitive timeline for baseline and post-concussion ImPACT testing. It is recommended that ImPACT should not be administered immediately after practice, competition, or after sustaining a concussion due to the acute physiological effects exercise may play on an individual's neurocognitive function. Further studies should continue to examine the psychometrics of the ImPACT software, as well as attempt to gain better understanding of the effects of exercise on neurocognitive function.

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APPENDIX A

University Committee for Research Involving Human Subjects (UCRIHS) Approval Form

MICHIGAN STATE
UNIVERSITY

Revision Application Approval

September 28, 2005

To: John POWELL
105 IM Sports Circle
MSU

Re: **IRB # 05-651** Category: EXPEDITED 2-4, 2-7
Revision Approval Date: September 28, 2005
Project Expiration Date: September 25, 2006

Title: THE EFFECTS OF STRENUOUS TREADMILL EXERCISE ON COGNITIVE FUNCTION IN RECREATIONAL ATHLETES

The University Committee on Research Involving Human Subjects (UCRIHS) has completed their review of your project. I am pleased to advise you that **the revision has been approved.**

Revision to include changes to the consent form. The new consent form is to replace the previously approved consent.

The review by the committee has found that your revision is consistent with the continued protection of the rights and welfare of human subjects, and meets the requirements of MSU's Federal Wide Assurance and the Federal Guidelines (45 CFR 46 and 21 CFR Part 50). The protection of human subjects in research is a partnership between the IRB and the investigators. We look forward to working with you as we both fulfill our responsibilities.

Renewals: UCRIHS approval is valid until the expiration date listed above. If you are continuing your project, you must submit an ***Application for Renewal*** application at least one month before expiration. If the project is completed, please submit an ***Application for Permanent Closure***.

Revisions: UCRIHS must review any changes in the project, prior to initiation of the change. Please submit an ***Application for Revision*** to have your changes reviewed. If changes are made at the time of renewal, please include an ***Application for Revision*** with the renewal application.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems, adverse events, or any problem that may increase the risk to the human subjects, notify UCRIHS promptly. Forms are available to report these issues.

Please use the IRB number listed above on any forms submitted which relate to this project, or on any correspondence with UCRIHS.

Good luck in your research. If we can be of further assistance, please contact us at 517-355-2180 or via email at UCRIHS@msu.edu. Thank you for your cooperation.

Sincerely,

Peter Vasilenko, Ph.D.
UCRIHS Chair

c: Leigh Weiss

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APPENDIX B

Human Subjects Consent Form

The Effects of Strenuous Treadmill Exercise on Cognitive Function in Recreational Athletes

Informed Consent

For questions regarding this study, Please contact:
Dr. John Powell, ATC
Department of Kinesiology
Michigan State University
Phone: (517) 432-5018
E-mail: powellj4@msu.edu or

Leigh J. Weiss, ATC
Graduate Assistant
Michigan State University
Email: weisslei@msu.edu
Phone: (848) 228-0246
Work: (517) 353-1655

For questions regarding your rights as a research participant, please contact:
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Phone: (517) 355-2180
Fax: (517) 432-4503

The purpose of this study is to examine the effects of strenuous treadmill exercise on an individual's neurocognitive function; specifically, memory, concentration, processing speed, and reaction time. The study will use the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) computer program as an assessment tool. In this study, ImPACT will be used to test your short and long term memory, concentration level, processing speed, and reaction time following strenuous treadmill exercise.

Your participation in this study will consist of one initial 30 minute orientation and training session and three days later, you will participate in a 90 minute testing session that includes the treadmill activity. Following the 90 minute testing session, you will be asked to return in three days for a 30 minute follow-up session. The first session will be used as an orientation and practice session to allow you to become familiar with the ImPACT software and the research protocol. If you have been assigned to the experimental group, the second session will consist of the baseline ImPACT test, a strenuous treadmill exercise until maximal oxygen uptake (VO2 max) is reached and another ImPACT test following the treadmill activity. If you have been assigned as a member of the control group, the second session will consist of an ImPACT test and period of inactivity during which you will be required to remain in the testing area during another subject's treadmill test. Both members of the control and experimental groups will participate in the third session that consists of an administration of the ImPACT test.

For the experimental subjects, the maximal exercise treadmill test will be done on a motorized treadmill. You will begin the test at a walking pace of 2.5 miles per hour. Each minute the speed of the treadmill will be increased .5 miles per hour until 6.0 mph is reached. Once 6.0 mph is reached, the grade of the treadmill will increase 3.0% each minute until VO2 max is obtained. During the exercise you will wear a nose-clip and breathe through a mouthpiece so that your expired air can be collected and analyzed by a metabolic measurement system. This enables investigators to determine how much oxygen you are using, how much carbon dioxide you are producing and how much air you are breathing. Immediately following the exercise, the ImPACT protocol will be administered again. Three days after the second session, you will be given the ImPACT protocol without the treadmill test.

It is impossible for the risk of injury to be completely eliminated during physical activity. The risk associated with the exercise portion of the protocol includes dizziness, muscle and/or joint pain, shortness of breath and, in extremely rare cases, heart attack, stroke and death. Measures will be taken during the test to ensure your safety throughout the research protocol. A certified athletic trainer will be on-site at all times during the testing session. An automated external defibrillator will be on hand. If there is any point during the treadmill test when you feel like you cannot continue please let the investigator know and the test will be terminated.

The benefits that come from your participation will help further advancements in understanding the neurocognitive effects of exercise. Subjects assigned to the experimental group will undergo a VO2 maximal exercise test as a measure of their cardio-respiratory endurance and fitness. The results of this test will be provided to you at the conclusion of the session.

Participation in this study is completely voluntary. Your identity and information recorded during the study will remain confidential. Confidentiality will be protected by; (a) results will be presented in aggregate form in any presentations and publications; and (b) all data will be stored in a computer that has a password necessary to see confidential data. Your privacy will be protected to the maximum extent allowable by law. You may also discontinue participation at any time without penalty. Your participation in this research project will not involve any additional costs to you or your health care insurer.

If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or are in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Dr. John Powell at 517-432-5018 with any questions or to report an injury.

Any questions concerning participation in this study should be directed to Leigh J. Weiss (848) 228-0246 or Dr. John Powell (517) 432-5018. If you have any additional questions concerning your rights as a volunteer or are dissatisfied at any time with any aspect of this study you may contact-anonymously, if you wish- Peter Vasilenko, PhD, Michigan State University's Chair of the Committee on Research Involving Human Subjects by phone: (517) 355-2180, fax: (517) 432-4503, e-mail: ucrihs@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.

INFORMED CONSENT

Your signature below indicates your voluntary agreement to participate in this study.

I, ____________________________ have read and agree to participate in this study as
(Please Print Your Name)
described above.

____
(Please Print Your Name)

____________________________ ____/____/____
(Please Sign Your Name) *(Date)*

UCRIHS APPROVAL FOR
THIS project EXPIRES:

SEP 2 5 2006

SUBMIT RENEWAL APPLICATION
ONE MONTH PRIOR TO
ABOVE DATE TO CONTINUE

APPENDIX C

Health History Questionnaire

The Effects of Strenuous Treadmill Exercise on Cognitive Function in Recreational Athletes

Contact Information Form

Subject Name: ______________________ **Age:** __________

Contact Phone Number: ______________________ **Height:** __________

Email Address: ______________________ **Weight:** __________

Exclusion Criteria Questionnaire

Please answer the following questions regarding your current activity level.

Are you currently on a varsity athletic team? Y N

How many days a week do you participate in athletic activity? __________

Describe what types of activities you are currently involved with:

____

____

____

____

____

Please answer the following questions regarding your health history.

Have you: (Circle your response)

Had a lower extremity injury within the last six months?	Y	N
Had a lower extremity surgery within the last year?	Y	N
Had a concussion in the last year?	Y	N
Ever been diagnosed with asthma?	Y	N
Been diagnosed or hospitalized for a cardiovascular condition?	Y	N
Been hospitalized for a respiratory illness?	Y	N
Ever been diagnosed with hypertension?	Y	N
Ever been diagnosed with ADD/ADHD?	Y	N
Ever been diagnosed with a learning disability?	Y	N
Ever been diagnosed as color blind?	Y	N

Have you or anyone in your family even been diagnosed with cardiovascular disease, hypertension, or respiratory ailments? Y N

If answered yes, please explain: ____

____

____

Is there any reason that you can identify that you would not be able to complete the treadmill activity related to this project? Y N

Thank you for your participation. Answers to this questionnaire will remain confidential. If you are not selected for this study, or choose not to participate your questionnaire will be shredded.

Signature: ______________________ **Date:** __________

MICHIGAN STATE UNIVERSITY
HUMAN ENERGY RESEARCH LABORATORY
EXERCISE PROGRAM/TESTING READINESS QUESTIONNAIRE

Every participant must fill out this questionnaire and sign a release before he/she will be allowed to participate in an exercise program and/or exercise testing activity sponsored by the Human Energy Research Laboratory. If you are under 18 years of age, a parent or legal guardian must sign the form on your behalf. If you are a man (woman) over 40 (50), under 40 (50) and physically inactive, your physician must also sign this form indicating your ability to participate in the exercise program or test indicated.

Name ______________________ **Phone** ____________ **Date** ________

Address ______________________ **Date of Birth** ________

Email ______________________ **Ht** _____ **Wt** _____

___Yes ___No 1. **Has your doctor ever said you have heart trouble?**

___Yes ___No 2. **Have you ever had chest pain or heavy pressure in your chest as a result of exercise, walking, or other physical activity, such as climbing a flight of stairs? (Note: This does not include the normal out-of-breath feeling that results from vigorous exercise)**

___Yes ___No 3. **Do you often feel faint or experience severe dizziness?**

___Yes ___No 4. **Has a doctor ever told you that you have high blood pressure or diabetes?**

___Yes ___No 5. **Have you ever had a real or suspected heart attack or stroke?**

___Yes ___No 6. **Do you have any physical condition, impairment or disability, including any joint or muscle problem, that should be considered before you undertake an exercise program?**

___Yes ___No 7. **Have you ever taken medication to reduce your blood pressure or cholesterol levels?**

___Yes ___No 8. **Are you excessively overweight?**

___Yes ___No 9. **Is there any good physical reason not mentioned here why you should not follow an exercise program even if you wanted to?**

___Yes ___No 10. **Are you over age 40, or not accustomed to vigorous exercise?**

If you answered YES to one or more questions, and if you have not recently done so, consult with your physician BEFORE entering an exercise program or participating in an exercise test. After medical evaluation or consultation, have your physician sign this form indicating your suitability for the following activity:

____

____

____

______________________ ________ ______________
Signature of Physician Date Phone

APPENDIX D

ImPACT Neuropsychological Test Battery Clinical Report

Experimental Group Subject 1

Organization:	MSU
Subject ID#:	123-45-6789

Date of birth:	11/26/84	Age:	21
Gender:	Male	Height:	75 inches
Handedness:	Right	Weight:	180 lbs

Native country / region:		Second language:	
Native language:		Years speaking:	0

Years of education completed excluding kindergarten:	14	Received speech therapy:	No
Diagnosed learning disability:	No	Problems with ADD/Hyperactivity:	No
Attended special education classes:	No	Repeated one or more years of school:	No

Current sport:	Football	Current level of participation:	Collegiate
Primary position/event/class:		Years experience at this level:	0

Number of times diagnosed with a concussion (excluding current injury):	0
Concussions that resulted in loss of conciousness:	0
Concussions that resulted in confusion:	0
Concussions that resulted in difficulty remembering events that occured immediately after injury:	0
Concussions that resulted in difficulty remembering events that occured	0
Total games missed as a result of all concussions combined:	0

Concussion history: 10/05/2005

Treatment for headaches by physician:	No	Treatment for psychiatric condition (depression, anxiety):	No
Treatment for epilepsy / seizures:	No	Treatment for migraine headaches by physician:	No
History of brain surgery:	No	Treatment for substance/alcohol abuse:	No
History of meningitis:	No		

Exam Type	Baseline	Post-concussion	Post-concussion	Post-concussion		
Date Tested	11/03/2005	11/07/2005	11/07/2005	11/10/2005		
Last Concussion		10/05/2005	10/05/2005	10/05/2005		
Headache	0	1	0	0		
Nausea	0	0	0	0		
Vomiting	0	0	0	0		
Balance Problems	0	2	0	0		
Dizziness	0	0	0	0		
Fatigue	0	5	0	0		
Trouble falling asleep	0	0	0	0		
Sleeping more than usual	0	0	0	0		
Sleeping less than usual	0	1	2	0		
Drowsiness	0	0	0	0		
Sensitivity to light	0	0	0	0		
Sensitivity to noise	0	0	0	0		
Irritability	0	0	0	0		
Sadness	0	0	0	0		
Nervousness	0	0	0	0		
Feeling more emotional	0	0	0	0		
Numbness or tingling	0	0	0	0		
Feeling slowed down	0	0	0	0		
Feeling mentally foggy	0	0	0	0		
Difficulty concentrating	0	0	0	0		
Difficulty remembering	0	0	0	0		
Visual problems	0	0	0	0		
Total Symptom Score	**0**	**9**	**2**	**0**		

Exam Type	Baseline	Post-concussion	Post-concussion	Post-concussion		
Date Tested	11/03/2005	11/07/2005	11/07/2005	11/10/2005		
Last Concussion		10/05/2005	10/05/2005	10/05/2005		
Exam Language	English	English	English	English		
Test Version	4.5.729	4.5.729	4.5.729	4.5.729		

Composite Scores *						
Memory composite (verbal)	85 34%	92 65%	87 41%	82 22%		
Memory composite (visual)†	86 77%	100 99%	99 99%	83 67%		
Visual motor speed composite	50.78 97%	**45.00** 86%	**43.48** 81%	52.48 99%		
Reaction time composite	0.42 98%	0.38 98%	0.41 98%	0.40 98%		
Impulse control composite	19	19	6	8		
Total Symptom Score	0	9	2	0		

Exam Type	Baseline	Post-concussion	Post-concussion	Post-concussion		
Date Tested	11/03/2005	11/07/2005	11/07/2005	11/10/2005		
Last Concussion		10/05/2005	10/05/2005	10/05/2005		

Word Memory	***WG = 1***	***WG = 3***	***WG = 2***	***WG = 4***		
Hits (immediate)	12	11	12	12		
Correct distractors (immed.)	12	11	12	12		
Learning percent correct	100%	92%	100%	100%		
Hits (delay)	12	11	11	8		
Correct distractors (delay)	12	9	10	12		
Delayed memory pct. correct	100%	83%	88%	83%		
Total percent correct	100%	88%	94%	92%		

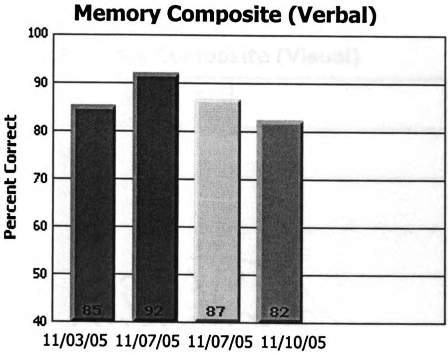
Design Memory						
Hits (immediate)	12	12	11	12		
Correct distractors (immed.)	12	12	12	12		
Learning percent correct	100%	100%	96%	100%		
Hits (delay)	12	12	12	12		
Correct distractors (delay)	11	12	12	12		
Delayed memory pct. correct	96%	100%	100%	100%		
Total percent correct	98%	100%	98%	100%		

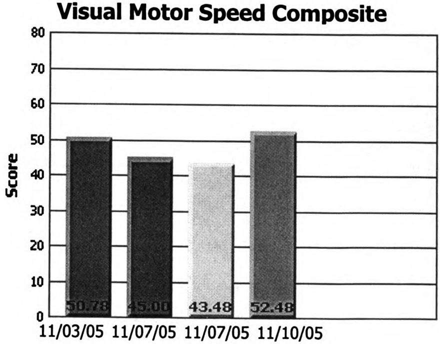
X's and O's						
Total correct (memory)	9	12	12	8		
Total correct (interference)	135	132	139	139		
Avg. correct RT (interference)	0.31	0.31	0.33	0.33		
Total incorrect (interference)	15	18	5	7		
Avg. incorrect RT (interfer.)	0.24	0.24	0.25	0.27		

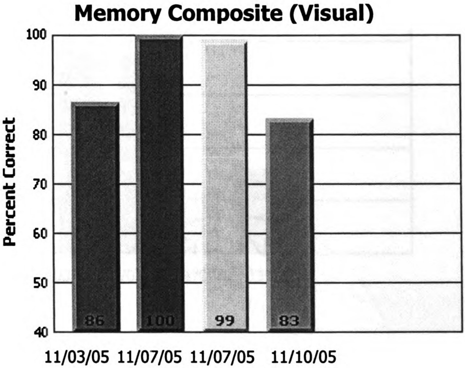
Symbol Match						
Total correct (visible)	27	27	27	27		
Avg. correct RT (visible)	0.92	1.09	1.08	1.21		
Total correct (hidden)	5	8	6	5		
Avg. correct RT (hidden)	0.91	1.45	1.65	1.49		

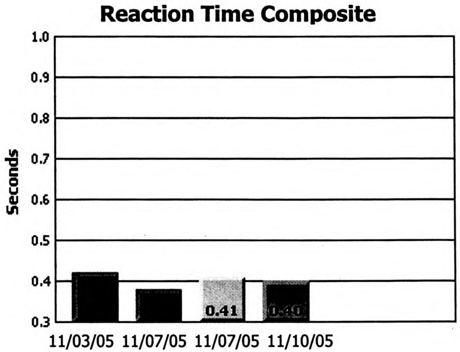
Color Match						
Total correct	9	9	9	9		
Avg. correct RT	0.65	0.47	0.53	0.47		
Total commissions	4	1	1	1		
Avg. commissions RT	0.87	0.41	0.47	0.42		

Three Letters						
Total sequence correct	5	5	5	5		
Total letters correct	15	15	15	15		
Pct. of total letters correct	100%	100%	100%	100%		
Avg. time to first click	2.01	1.74	1.95	1.35		
Avg. counted	22.6	19.2	18.0	23.4		
Avg. counted correctly	22.6	19.0	17.4	23.4		

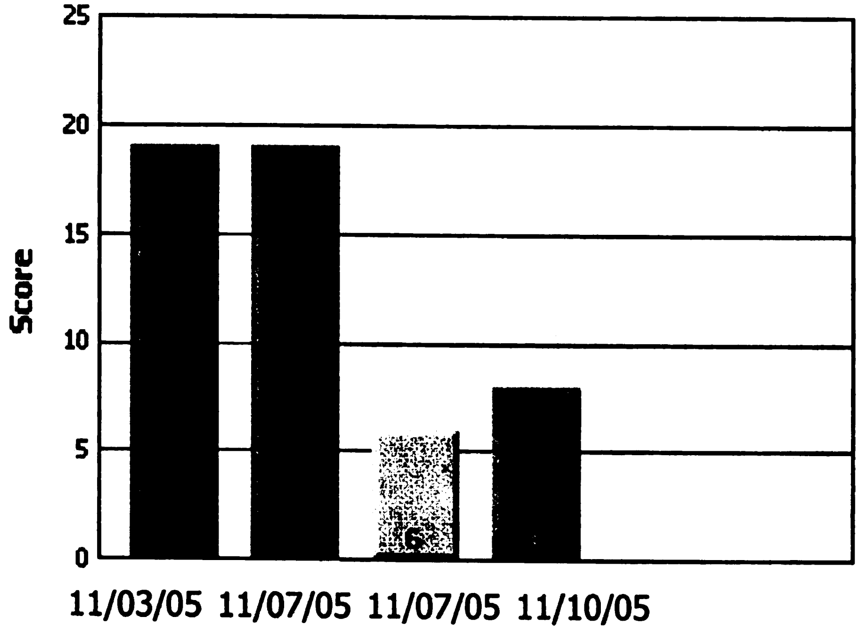

Memory Composite (Verbal)
100
90
80
70
60
50
40
Percent Correct
85
92
87
82
11/03/05 11/07/05 11/07/05 11/10/05


Visual Motor Speed Composite
80
70
60
50
40
30
20
10
0
Score
50.78
45.00
43.48
52.48
11/03/05 11/07/05 11/07/05 11/10/05

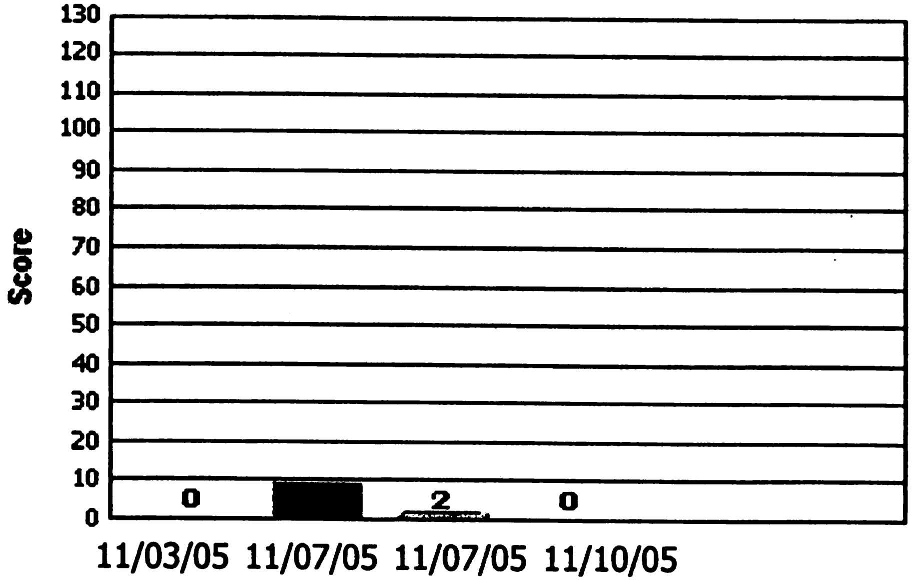

Memory Composite (Visual)
Percent Correct
100
90
80
70
60
50
40
86
100
99
83
11/03/05 11/07/05 11/07/05 11/10/05


Reaction Time Composite
Seconds
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.41
11/03/05 11/07/05 11/07/05 11/10/05

Impulse Control Composite



Symptom Score



APPENDIX E

DESCRIPTIVE STATISTICS AND ANOVAS FOR ImPACT CLNINCAL COMPOSITE SCORES

Table 7 Descriptive Statistics for Self-Reported Fatigue Scores

Time	N	Mean	Std. Deviation
Practice			
Experimental			
Male	27	.67	1.17
Female	27	.67	1.27
Total	54	.67	1.21
Control			
Male	23	.43	.99
Female	25	1.00	1.53
Total	48	.73	1.32
Baseline			
Experimental			
Male	27	.44	.80
Female	27	.59	1.12
Total	54	.52	.99
Control			
Male	23	.39	.84
Female	25	1.12	1.64
Total	48	.77	1.36
Post-Test 1			
Experimental			
Male	27	3.96	1.19
Female	27	4.07	1.17
Total	54	4.02	1.17
Control			
Male	23	.30	.70
Female	25	1.16	1.72
Total	48	.75	.14
Post-Test 2			
Experimental			
Male	27	.59	1.42
Female	27	.63	1.36
Total	54	.61	1.37
Control			
Male	23	.52	.95
Female	25	.52	1.01
Total	48	.52	.97

Table 8 Descriptive Statistics for Verbal Memory Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.87	.09	.84-.90
Female	27	.89	.06	.86-.92
Total	54	.88	.08	
Control				
Male	23	.88	.08	.84-.91
Female	25	.89	.08	.86-.92
Total	48	.88	.09	
Post-Test 1				
Experimental				
Male	27	.80	.12	.77-.84
Female	27	.84	.09	.80-.88
Total	54	.82	.11	
Control				
Male	23	.87	.10	.83-.92
Female	25	.87	.11	.83-.91
Total	48	.87	.10	
Post-Test 2				
Experimental				
Male	27	.87	.10	.83-.90
Female	27	.87	.09	.83-.90
Total	54	.87	.10	
Control				
Male	23	.89	.09	.85-.93
Female	25	.88	.09	.85-.92
Total	48	.89	.09	

Table 9 Repeated Measures ANOVA Comparing Verbal Memory Composite Scores for Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time x Exercise	.03	2	.01	3.75	.03*
Time x Gender	.07	2	.00	.97	.38
Time x Exercise x Gender	.01	2	.00	.78	.46

*(significant at p = .05)

Table 10 One-way Repeated Measures ANOVA Comparing Verbal Memory Composite Scores For the Experimental and Control Groups

Exercise Group	SS	df	MS	F	p
Experimental	.10	2	.05	14.78	.00*
Control	.01	2	.00	1.14	.33

*(significant at the p = .05 level)

Table 11 Pairwise Comparison for Verbal Memory Composite Scores for the Experimental Group

Verbal	Mean Differences	Standard Error	p
Baseline to Post-test 1	.06	.01	.00*
Baseline to Post-test 2	.01	.01	.23
Post-test 1 to Baseline	-.06	.01	.00*
Post-test 1 to Post-Test 2	-.04	.01	.00*
Post-test 2 to Baseline	-.01	.01	.23
Post-test 2 to Post-test 1	.04	.01	.00*

*(significant at the p = .05 level)

Table 12 Pairwise Comparison for Verbal Memory Composite Scores for the Control Group

Verbal	Mean Differences	Standard Error	p
Baseline to Post-test 1	.01	.01	.26
Baseline to Post-test 2	-.03	.01	.78
Post-test 1 to Baseline	-.01	.01	.26
Post-test 1 to Post-test 2	-.01	.01	.18
Post-test 2 to Baseline	.00	.01	.78
Post-test 2 to Post-test 1	.01	.01	.18

Table 13 Descriptive Statistics for Immediate Word Recall Memory

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.96	.05	.94-.97
Female	27	.98	.04	.96-.99
Total	54	.97	.04	
Control				
Male	23	.96	.04	.94-.98
Female	25	.97	.06	.95-.99
Total	48	.97	.05	
Post-Test 1				
Experimental				
Male	27	.90	.12	.87-.93
Female	27	.92	.08	.89-.95
Total	54	.91	.10	
Control				
Male	23	.97	.05	.93-1.00
Female	25	.96	.08	.92- .99
Total	48	.96	.07	
Post-Test 2				
Experimental				
Male	27	.95	.06	.93-.98
Female	27	.96	.04	.94-.99
Total	54	.96	.05	
Control				
Male	23	.95	.06	.93-.98
Female	25	.95	.06	.92-.97
Total	48	.95	.06	

Table 14 Repeated Measures ANOVA Comparing Immediate Word Recall Memory for Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time x Exercise	.05	2	.01	7.76	.00*
Time x Gender	.04	2	.00	.53	.66
Time x Exercise x Gender	.00	2	.00	.37	.77

*(significant at p = .05)

Table 15 One-way Repeated Measures ANOVA Comparing Immediate Word Recall Memory Scores for the Experimental and Control Groups

Exercise Group	SS	df	MS	F	p
Experimental	.11	2	.05	16.45	.00*
Control	.01	2	.00	1.80	.17

*(significant at the p = .05 level)

Table 16 Pairwise Comparison for Immediate Word Recall Memory for the Experimental Group

Delayed Recall	Mean Differences	Standard Error	p
Baseline to Post-test 1	.05	.01	.00*
Baseline to Post-test 2	.01	.01	.33
Post-test 1 to Baseline	-.05	.01	.00*
Post-test 1 to Post-Test 2	-.04	.01	.00*
Post-test 2 to Baseline	-.01	.01	.31
Post-test 2 to Post-test 1	.04	.01	.00*

*(significant at the p = .05 level)

Table 17 Descriptive Statistics for Delayed Recall Word Memory

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.84	.14	.80-.87
Female	27	.87	.11	.83-.92
Total	54	.86	.13	
Control				
Male	23	.86	.13	.81-.90
Female	25	.89	.09	.85-.94
Total	48	.87	.11	
Post-Test 1				
Experimental				
Male	27	.77	.15	.72-.82
Female	27	.80	.13	.75-.85
Total	54	.78	.14	
Control				
Male	23	.88	.12	.83-.93
Female	25	.87	.11	.82-.92
Total	48	.88	.11	
Post-Test 2				
Experimental				
Male	27	.81	.16	.76-.86
Female	27	.85	.10	.80-.90
Total	54	.83	.14	
Control				
Male	23	.83	.12	.77-.88
Female	25	.83	.14	.78-.88
Total	48	.83	.13	

Table 18 Repeated Measures ANOVA Comparing Delayed Recall Word Memory for Gender, Time, and Exercise

Neurocognitive Function	SS	Df	MS	F	p
Time x Exercise	.12	2	.04	5.00	.00*
Time x Gender	.00	2	.02	.26	.85
Time x Exercise x Gender	.01	2	.00	.60	.61

*(significant at p = .05)

Table 19 One-way Repeated Measures ANOVA Comparing Delayed Recall Word Memory Scores for the Experimental and Control Groups

Exercise Group	SS	Df	MS	F	p
Experimental	.14	2	.07	6.94	.00*
Control	.07	2	.04	4.88	.01*

*(significant at the p = .05 level)

Table 20 Pairwise Comparison for Delayed Recall Word Memory for the Experimental Group

Delayed Recall	Mean Differences	Standard Error	p
Baseline to Post-test 1	.07	.02	.00*
Baseline to Post-test 2	.03	.02	.11
Post-test 1 to Baseline	-.07	.02	.00*
Post-test 1 to Post-Test 2	-.04	.02	.04
Post-test 2 to Baseline	-.03	.02	.11
Post-test 2 to Post-test 1	.04	.02	.04

*(significant at the p = .05 level)

Table 21 Pairwise Comparison for Delayed Recall Word Memory for the Control Group

Delayed Recall	Mean Differences	Standard Error	p
Baseline to Post-test 1	.00	.02	.79
Baseline to Post-test 2	.05	.02	.03*
Post-test 1 to Baseline	.00	.02	.79
Post-test 1 to Post-Test 2	.05	.02	.01*
Post-test 2 to Baseline	-.05	.02	.03*
Post-test 2 to Post-test 1	.05	.02	.01*

*(significant at the p = .05 level)

Table 22 Descriptive Statistics for Symbol Match with Key

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	26.70	.82	26.52-26.89
Female	27	26.96	.19	26.78-27.15
Total	54	26.83	.61	
Control				
Male	23	26.91	.29	26.71-27.11
Female	25	26.88	.33	26.69-27.07
Total	48	26.90	.31	
Post-Test 1				
Experimental				
Male	27	26.89	.42	26.77-27.01
Female	27	26.85	.36	26.74-26.97
Total	54	26.87	.39	
Control				
Male	23	26.96	.21	26.83-27.08
Female	25	27.00	.00	26.88-27.12
Total	48	26.98	.14	
Post-Test 2				
Experimental				
Male	27	26.93	.27	26.81-27.05
Female	27	26.96	.19	26.84-27.08
Total	54	26.94	.23	
Control				
Male	23	26.78	.52	26.65-26.91
Female	25	26.96	.20	26.84-27.09
Total	48	26.88	.39	

Table 23 Repeated Measures ANOVA Comparing Symbol Match (With Key) for Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time x Exercise	.50	2	.17	1.16	.32
Time x Gender	.21	2	.07	.49	.69
Time x Exercise x Gender	.71	2	.24	1.65	.18

Table 24 Descriptive Statistics for Symbol Match Score (Without Key)

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	6.70	1.84	6.02-7.39
Female	27	6.93	1.69	6.24-7.61
Total	54	6.81	1.75	
Control				
Male	23	6.87	1.74	6.13-7.61
Female	25	7.20	1.89	6.49-7.91
Total	48	7.04	1.81	
Post-Test 1				
Experimental				
Male	27	5.89	2.34	5.08-6.70
Female	27	6.59	1.93	5.78-7.40
Total	54	6.24	2.15	
Control				
Male	23	6.52	1.95	5.64-7.40
Female	25	6.36	2.22	5.52-7.20
Total	48	6.43	2.07	
Post-Test 2				
Experimental				
Male	27	6.93	2.04	6.21-7.65
Female	27	6.40	1.74	5.69-7.13
Total	54	6.67	1.89	

Table 25 Repeated Measures ANOVA Comparing Symbol Match (Without Key) for Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time x Exercise	3.36	2	1.12	.52	.67
Time x Gender	12.11	2	4.04	1.89	.13
Time x Exercise x Gender	6.60	2	2.20	1.03	.38

Table 26 Descriptive Statistics for the 3-Letter Recall Task

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	14.37	1.04	13.99-14-75
Female	27	14.52	1.05	14.14-14.90
Total	54	14.44	1.04	
Control				
Male	23	14.60	.89	14.20-15.02
Female	25	14.36	.95	13.97-14.75
Total	48	14.48	.92	
Post-Test 1				
Experimental				
Male	27	14.22	1.34	13.70-14.74
Female	27	13.89	1.55	13.37-14.41
Total	54	14.06	1.45	
Control				
Male	23	14.17	1.47	13.61-14.74
Female	25	14.56	1.00	14.02-15.10
Total	48	14.37	1.25	
Post-Test 2				
Experimental				
Male	27	14.48	.94	14.13-14.83
Female	27	14.56	.93	14.21-14.90
Total	54	14.52	.93	
Control				
Male	23	14.52	.79	14.15-14.90
Female	25	14.56	.96	14.20-14.92
Total	48	14.54	.87	

Table 27 Repeated Measures ANOVA Comparing 3-Letter Recall for Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time x Exercise	1.93	2	.66	.56	.64
Time x Gender	.78	2	.26	.23	.88
Time x Exercise x Gender	4.14	2	1.38	1.21	.31

Table 28 Descriptive Statistics for Visual Memory Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.82	.10	.77-.86
Female	27	.74	.14	.69-.78
Total	54	.78	.13	
Control				
Male	23	.80	.10	.75-.85
Female	25	.78	.13	.73-.83
Total	48	.79	.12	
Post-Test 1				
Experimental				
Male	27	.84	.10	.79-.89
Female	27	.74	.15	.69-.78
Total	54	.79	.14	
Control				
Male	23	.83	.11	.78-.88
Female	25	.80	.13	.75-.85
Total	48	.81	.12	
Post-Test 2				
Experimental				
Male	27	.81	.11	.76-.86
Female	27	.78	.11	.73-.83
Total	54	.80	.11	
Control				
Male	23	.77	.16	.72-.83
Female	25	.82	.13	.77-.87
Total	48	.80	.15	

Table 29 Repeated Measures ANOVA for Visual Memory Composite Scores comparing Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time x Exercise	.00	2	.00	.62	.54
Time x Gender	.09	2	.04	5.85	.00*
Time x Exercise x Gender	.00	2	.00	.09	.91

*(significant at the p = .05 level)

Table 30 Descriptive Statistics for Motor Processing Speed Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	43.27	6.17	40.81-45.71
Female	27	42.13	6.83	39.68-44.57
Total	54	42.70	6.47	
Control				
Male	23	43.81	6.86	41.16-46.54
Female	25	42.62	5.66	40.09-45.16
Total	48	43.19	6.22	
Post-Test 1				
Experimental				
Male	27	42.26	7.69	39.57-44.96
Female	27	43.71	7.43	41.02-46.40
Total	54	42.99	7.52	
Control				
Male	23	44.69	6.86	41.77-47.61
Female	25	44.07	6.00	41.27-46.87
Total	48	44.37	6.37	
Post-Test 2				
Experimental				
Male	27	45.68	7.53	42.91-48.45
Female	27	44.35	8.38	41.58-47.12
Total	54	45.02	7.92	
Control				
Male	23	44.79	7.23	41.79-47.79
Female	25	46.42	5.42	43.55-49.30
Total	48	45.64	6.34	

Table 31 Repeated Measures ANOVA for Motor Processing Speed Composite Scores comparing Gender, Time, Exercise

Neurocognitive Function	SS	Df	MS	F	p
Time x Exercise	11.98	2	5.99	.39	.68
Time x Gender	36.31	2	18.15	1.18	.31
Time x Exercise x Gender	81.61	2	40.81	2.65	.07

Table 32 Descriptive Statistics for Reaction Time Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.52	.05	.50-.54
Female	27	.53	.06	.51-.55
Total	54	.53	.06	
Control				
Male	23	.54	.05	.52-.56
Female	25	.52	.05	.50-.55
Total	48	.53	.05	
Post-Test 1				
Experimental				
Male	27	.50	.05	.48-.52
Female	27	.51	.05	.49-.53
Total	54	.51	.05	
Control				
Male	23	.53	.05	.52-.56
Female	25	.51	.04	.49-.53
Total	48	.52	.05	
Post-Test 2				
Experimental				
Male	27	.50	.04	.48-.52
Female	27	.50	.06	.48-.52
Total	54	.50	.05	
Control				
Male	23	.53	.05	.51-.56
Female	25	.50	.05	.48-.52
Total	48	.52	.06	

Table 33 Repeated Measures ANOVA for Reaction Time Composite Scores comparing Gender, Time and Exercise

Neurocognitive Function	SS	Df	MS	F	p
Time X Exercise	.00	2	.00	.82	.44
Time X Gender	.00	2	.00	1.48	.23
Time x Exercise x Gender	.00	2	.00	.49	.62

Table 34 Descriptive Statistics for Impulse Control Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	6.00	3.76	4.52-7.48
Female	27	5.37	5.00	3.89-6.85
Total	54	5.69	4.40	
Control				
Male	23	4.96	3.27	3.35-6.56
Female	25	5.16	3.04	3.62-6.70
Total	48	5.06	3.12	
Post-Test 1				
Experimental				
Male	27	6.44	5.05	4.88-8.40
Female	27	6.93	6.06	4.97-8.89
Total	54	6.69	5.53	
Control				
Male	23	6.43	5.27	4.13-8.56
Female	25	5.32	3.81	3.29-7.36
Total	48	5.85	4.55	
Post-Test 2				
Experimental				
Male	27	6.74	4.57	4.86-8.61
Female	27	7.52	6.52	5.64-9.40
Total	54	7.13	5.59	
Control				
Male	23	6.78	3.85	4.75-8.82
Female	25	5.88	4.06	3.93-7.83
Total	48	6.31	3.94	

Table 35 Repeated Measures ANOVA for Impulse Control Composite Scores comparing Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time X Exercise	.53	2	.26	.03	.97
Time X Gender	.83	2	.42	.04	.96
Time x Exercise x Gender	25.87	2	12.93	1.35	.26

APPENDIX F

Statistical Analysis of the Research Composite Scores

The ImPACT 2005 software has added five additional composite scores to aid with clinical research studies. These five research composite scores include: the immediate memory composite score, the delayed memory composite score, the working memory composite score, the X's and O's speed index, and the symbol match memory speed index. These five scores have not yet been validated by research and should not be used for return-to-play decision. Table 3-3 illustrates how the research composite scores are derived from the individual test modules.

Table 36 ImPACT Research Composite Scores

Composite Scores	Contributing Scores
Immediate Memory Composite	Learning Percent Correct from Word Memory and Design Modules
Delayed Memory	Average of the Delayed Memory Percent scores from Word Memory and Design Memory Modules
Working Memory	Average percent correct of the X's and O's Total Correct, the Symbol Match Total Correct, and the Total Sequence Correct and Three Letters score
X's and O's Memory-Speed Index	X's and O's Memory Percent Correct x (2 - Average Correct Reaction Time)
Symbol Match Memory Speed Index	(1 - Average Correct Reaction Time/3) * Symbol Match Correct (hidden)

(Lovell, et al., 2005)

Table 37 Descriptive Statistics for Immediate Memory Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.91	.06	.89-.94
Female	27	.90	.07	.87-.92
Total	54	.90	.06	
Control				
Male	23	.91	.06	.88-.93
Female	25	.92	.06	.90-.95
Total	48	.91	.06	
Post-Test 1				
Experimental				
Male	27	.88	.10	.85-.92
Female	27	.90	.09	.87-.93
Total	54	.89	.09	
Control				
Male	23	.93	.07	.89-.96
Female	25	.93	.08	.90-.97
Total	48	.93	.08	
Post-Test 2				
Experimental				
Male	27	.92	.07	.89-.94
Female	27	.93	.06	.91-.96
Total	54	.92	.06	
Control				
Male	23	.92	.07	.89-.95
Female	25	.93	.08	.89-.95
Total	48	.93	.08	

Table 38 Repeated Measures ANOVA for Immediate Memory Composite Scores comparing Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time X Exercise	.03	2	.01	5.38	.01*
Time X Gender	.00	2	.00	.18	.84
Time x Exercise x Gender	.00	2	.00	1.54	.22

*(significant at the p = .05 level)

Table 39 One-way ANOVA Comparing Immediate Memory Composite Scores For Exercise Groups

Time	SS	df	MS	F	p
Experimental	.03	2	.02	7.25	.00*
Control	.00	2	.00	1.03	.36

*(significant at the p = .05 level)

Table 40 Pairwise Comparison for Immediate Memory Composite Scores in the Experimental Group

Time	Mean Differences	Standard Error	p
Baseline to Post-test 1	.01	.01	.15
Baseline to Post-test 2	-.02	.01	.01*
Post-test 1 to Baseline	-.01	.01	.15
Post-test 1 to Post-test 2	-.03	.01	.00*
Post-test 2 to Baseline	.02	.01	.01*
Post-test 2 to Post-test 1	.03	.01	.00*

*(significant at the p = .05 level)

Table 41 Pairwise Comparison for Immediate Memory Composite Scores in the Control Group

Time	Mean Differences	Standard Error	p
Baseline to Post-test 1	-.01	.01	.15
Baseline to Post-test 2	-.00	.01	.75
Post-test 1 to Baseline	.01	.01	.15
Post-test 1 to Post-test 2	.01	.01	.28
Post-Test 2 to Baseline	.00	.01	.75
Post-test 2 to Post-test 1	-.01	.01	.28

Table 42 Descriptive Statistics for Delayed Memory Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.83	.10	.80-.87
Female	27	.83	.09	.80-.87
Total	54	.83	.10	
Control				
Male	23	.83	.10	.78-.86
Female	25	.86	.07	.82-.89
Total	48	.84	.09	
Post-Test 1				
Experimental				
Male	27	.79	.10	.75-.83
Female	27	.81	.09	.76-.85
Total	54	.80	.10	
Control				
Male	23	.88	.10	.83-.92
Female	25	.86	.07	.81-.90
Total	48	.87	.09	
Post-Test 2				
Experimental				
Male	27	.81	.12	.77-.85
Female	27	.84	.09	.80-.88
Total	54	.83	.11	
Control				
Male	23	.82	.12	.78-.87
Female	25	.83	.11	.79-.87
Total	48	.83	.11	

Table 43 Repeated Measures ANOVA for Delayed Memory Composite Scores comparing Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time X Exercise	.02	2	.04	7.57	.01*
Time X Gender	.02	2	.00	.52	.60
Time x Exercise x Gender	.01	2	.00	1.79	.17

*(significant at the p = .05 level)

Table 44 One-way Repeated Measures ANOVA Comparing Delayed Memory Composite Scores for the Exercise Group

Time	SS	df	MS	F	p
Experimental	.04	2	.02	3.71	.03*
Control	.04	2	.02	4.13	.02*

*(significant at the p = .05 level)

Table 45 Pairwise Comparison for Delayed Memory Composite Scores in the Experimental Group

Time	Mean Differences	Standard Error	p
Baseline to Post-Test 1	.03	.01	.02*
Baseline to Post-Test 2	.00	.01	.58
Post-Test 1 to Baseline	-.03	.01	.02*
Post-Test 1 to Post-Test 2	-.02	.01	.04*
Post-Test 2 to Baseline	.00	.01	.58
Post-Test 2 to Post-Test 1	.02	.01	.04*

*(significant at the p = .05 level)

Table 46 Pairwise Comparison for Delayed Memory Composite Scores in the Control Group

Time	Mean Differences	Standard Error	p
Baseline to Post-Test 1	-.03	.01	.04*
Baseline to Post-Test 2	.01	.02	.46
Post-Test 1 to Baseline	.03	.01	.04*
Post-Test 1 to Post-Test 2	.04	.01	.01*
Post-Test 2 to Baseline	-.01	.02	.46
Post-Test 2 to Post-Test 1	-.04	.01	.01*

*(significant at the p = .05 level)

Table 47 Descriptive Statistics for Working Memory Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.71	.11	.67-.76
Female	27	.67	.12	.63-.72
Total	54	.69	.12	
Control				
Male	23	.71	.09	.66-.76
Female	25	.70	.12	.66-.75
Total	48	.71	.11	
Post-Test 1				
Experimental				
Male	27	.69	.10	.65-.73
Female	27	.66	.12	.62-.70
Total	54	.67	.11	
Control				
Male	23	.71	.09	.66-.76
Female	25	.68	.12	.64-.73
Total	48	.70	.11	
Post-Test 2				
Experimental				
Male	27	.71	.12	.67-.75
Female	27	.68	.10	.63-.72
Total	54	.69	.11	
Control				
Male	23	.70	.12	.65-.74
Female	25	.72	.11	.68-.77
Total	48	.71	.11	

Table 48 Repeated Measures ANOVA for Working Memory Composite Scores comparing Gender, Time, and Exercise

Neurocognitive Function	SS	df	MS	F	p
Time X Exercise	.00	2	.00	.12	.89
Time X Gender	.00	2	.00	.70	.49
Time x Exercise x Gender	.00	2	.00	.69	.50

Table 49 Descriptive Statistics for X's and O's Memory-Speed Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	1.29	.26	1.16-1.41
Female	27	1.07	.36	.94-1.19
Total	54	1.18	.33	
Control				
Male	23	1.26	.30	1.12-1.39
Female	25	1.15	.35	1.02-1.28
Total	48	1.20	.33	
Post-Test 1				
Experimental				
Male	27	1.37	.20	1.25-1.48
Female	27	1.21	.38	.92-1.15
Total	54	1.20	.34	
Control				
Male	23	1.26	.28	1.14-1.39
Female	25	1.21	.32	1.09-1.33
Total	48	1.23	.30	
Post-Test 2				
Experimental				
Male	27	1.24	.31	1.11-1.37
Female	27	1.16	.31	1.03-1.28
Total	54	1.20	.31	
Control				
Male	23	1.13	.38	.99-1.27
Female	25	1.27	.35	1.14-1.40
Total	48	1.20	.36	

Table 50 Repeated Measures ANOVA for X's and O's Speed-Memory Composite Scores comparing Gender, Time, and Exercise.

Neurocognitive Function	SS	df	MS	F	p
Time X Exercise	.01	2	.00	.10	.90
Time X Gender	.72	2	.36	4.98	.01*
Time x Exercise x Gender	.08	2	.05	.65	.52

*(significant at the p = .05 level)

Table 51 Descriptive Statistics for Symbol Match Memory Speed Composite Scores

Time	N	Mean	Std. Deviation	95% CI
Baseline				
Experimental				
Male	27	.35	.15	.29-.40
Female	27	.37	.13	.32-.43
Total	54	.36	.14	
Control				
Male	23	.33	.16	.27-.39
Female	25	.38	.14	.32-.44
Total	48	.36	.15	
Post-Test 1				
Experimental				
Male	27	.25	.15	.19-.31
Female	27	.34	.13	.29-.40
Total	54	.30	.15	
Control				
Male	23	.31	.14	.25-.37
Female	25	.30	.16	.24-.36
Total	48	.31	.15	
Post-Test 2				
Experimental				
Male	27	.37	.12	.32-.43
Female	27	.35	.15	.29-.40
Total	54	.36	.14	
Control				
Male	23	.37	.14	.31-.43
Female	25	.37	.17	.31-.43
Total	48	.37	.16	

Table 52 Repeated Measures ANOVA for Symbol Match Memory Speed Composite Scores comparing Gender, Time, and Exercise.

Neurocognitive Function	SS	df	MS	F	P
Time X Exercise	.00	2	.00	.14	.87
Time X Gender	.05	2	.00	1.68	.19
Time x Exercise x Gender	7.060E -02	2	.00	2.56	.08