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The research on the cognitive benefits of exercise has shown that regular participation in physical activity can improve performance for cognitive activities. Recently, animal research has shown that combining physical activity (PA) with cognitive training concomitantly, produces greater increases in cognitive performance than either done alone. The human research that has been designed to explore the effects of combined exercise and cognitive training has implemented the training on separate days and in separate locations. Thus, the human research has not looked at combining PA and cognitive engagement during exercise in the same way the animal research has. Therefore, the current study investigated the cognitive benefits of a cognitive training protocol performed during an exercise task as compared to cognitive training or exercise training alone.

Participants ($N = 24$) were randomized to one of three groups that engaged in a 6-day training protocol. There was a bike group that exercised at a moderate intensity, a game group that engaged in an interactive learning software protocol, and a both group that completed the interactive learning software protocol while simultaneously exercising. All participants were tested before and after the 6 day training session on the Wonderlic Personnel Test, the Stroop Test, the Trail Making Tests A and B (TMTA, TMTB) and the Paced Auditory Serial Addition Test (PASAT). The results of the Repeated Measures ANOVA for the Stroop test showed there was a significant interaction of time x test x group, $p < .05$ indicating that while the two exercise groups

(bike and both) had improvements in scores on all subtests over time, the game group did improve on the color subtest but did not improve on the word and color-word subtests. Analysis of the Stroop interference score also showed a significant time x group interaction, $p < .05$. Examination of the means showed that the bike group and the both group reduced their time to completion from pretest to posttest, but the game group increased their completion time and therefore performed worse at posttest. An examination of the set-switch score for the TMT indicated that the interaction of time x group approached significance, $p = .062$. Examination of the means indicated that the bike group and the both group reduced their time to completion from pretest to posttest, but the game group increased their completion time from pretest to posttest. The findings suggest that combining exercise and a cognitive training protocol can produce significant results on cognitive measures after a 6-day intervention.

PAIRING COGNITIVE TRAINING AND EXERCISE

by

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APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

Research has shown that exercise interventions can improve performance on cognitive tasks. Simple walking protocols improve face recognition and memory recall (Hassmen & Kiovula, 1997) and reduce behavioral conflict during cognitively-engaging activities (Colcombe et al., 2004). Light intensity physical activity (PA) also results in improvements in memory recall (Klusmann et al., 2010). In fact, numerous studies have been conducted to test the effects of PA on cognitive performance. When reviewed meta-analytically, small effects are observed for chronic exercise interventions on cognitive performance by the general population (Etnier et al., 1997) or by children (Sibley & Etnier, 2003) and moderate effects are observed for studies with older adults (Angevaren et al., 2008; Colcombe & Kramer, 2003; Heyn et al., 2004).

Although these results are promising, researchers have recently become interested in adding cognitive engagement to PA or exercise protocols in order to potentially increase the effect on cognitive outcomes. Results from an animal study provide initial evidence that combined PA and cognitive interventions produce the largest positive effects on cognitive performance. Black, Isaacs, Anderson, Alcantara and Greenough (1990) randomly assigned rats to either an acrobatic condition (AC), a forced exercise (FX) condition, a voluntary exercise (VX) condition, or an inactive condition (IC). The AC rats worked on progressively longer and more difficult trials of an elevated path that changed every day. The path consisted of bridges, see-saws, balance beams and other obstacles. Obstacles were added until they completed 5 trials of 7 obstacles a day. In the FX condition, rats walked at a 10 meter per minute pace for progressively longer periods of time until they reached one hour of daily walking. Rats in the VX condition had unlimited access to a running wheel. Rats in the IC condition were kept in a standard laboratory cage and had limited opportunities for learning or exercise. Results showed that the VX and FX groups had significantly greater blood vessel density compared to the AC and the IC group. However the AC group had significantly greater increases in Purkinje cell density and in the establishment of new synapses compared to all of the other groups. These findings suggest beneficial structural changes that could underlie effects on cognitive performance.

Lores-Arnaiz et al. (2006) looked at increases in cognitive performance on learning and working memory as a result of access to more enriched environments. Older rats were randomly assigned to an enriched environmental condition or a control condition. Rats in the control condition had only a water bottle and food cage. Rats in the enriched group had many cage furnishings such as a walkways, bridges, nests, and toys. Every day five new and different objects were provided to every enriched cage for 24 hours. When the rats were 90 days old, they participated in spatial working memory (WM) and long term memory (LTM) tests that required animals to perform a maze task with the possibility to have as many as eight arms open and with food at the end of 4 of the arms (baited arms). The rats were trained once a day to explore and locate the food reward at the end of each baited arm. The WM task had two phases. The first phase consisted of having 2 baited arms open where the rat could explore the maze for 5 minutes or until they found all of the food. In phase two all of the maze arms were open and the rats were able to explore the entire maze. The researchers tracked the rats' movements and recorded which arm the rats entered as well as time to completion. If the rat entered an arm that was open during phase one it was counted as a WM error because the food had already been eaten. If the rat entered into one of the non-baited arms from their training session then it was considered a LTM error. Results showed that the enriched rats had significantly more days of one or fewer WM errors compared to the control rats as well as significantly greater increases in WM performance and significantly reduced completion time of phase two. These results suggest that the difference in performance between the groups was indicative of effects of enrichment on learning.

Milgram et al. (2005) investigated behavioral enrichment to prevent age-related cognitive declines in beagle dogs for 9 months. The dogs were randomized to a behavioral enrichment environment or a control environment along with either a special or controlled diet. Dogs in the enriched groups received some cognitive measures and training on task differentiation and reversal learning. For example, enriched dogs learned a color difference task where they had to discern which of two objects was black in order to earn a food reward. Then they were tested later in the reversal learning condition by having to identify the white object. The dogs in the enriched condition also exercised twice a week in 15 minute intervals, were housed with 1-3 kennel mates, and were given a rotating set of toys that alternated weekly. Dogs in the control groups did not receive exercise or have access to toys and lived in a pen either alone or with 1 kennel mate. The results showed that the enrichment groups learned more accurately than the control groups and performed the color difference task significantly better than dogs in the control group. The authors concluded that the behavioral enrichment led to better learning and cognitive performance.

There are two human studies that have attempted to assess the effects of a combined PA and cognition intervention. Small et al. (2006) investigated the effects of a 14-day longevity lifestyle program on brain function and cognition. The 14-day longevity program detailed instructions and daily exercises for healthy lifestyle strategies. The lifestyle strategies included cognitive activities and daily physical activities. The participants engaged in brain teasers and other mind puzzles along with lessons on memory strategies and mnemonic techniques. The daily recommended PA included brisk walks that lasted up to 45minutes. Cognitive tests and brain imaging were given at baseline and follow up to assess any changes. The results showed that participants significantly improved on verbal fluency from the baseline measure compared to the control group. Imaging results for the positron emission tomography (PET) scan showed the longevity lifestyle participants also had a 5% significant reduction in brain activity for the left dorsolateral prefrontal activity. The dorsolateral prefrontal cortex is a location associated with working memory and mediates anxiety symptoms. The researchers report that the reduction in brain activity could be due to an increase in cognitive efficiency. Thus, these results suggest that a short-term combined exercise and cognitive training program improves verbal fluency and increases working memory efficiency as compared to a control condition.

Fabre, Chamari, Mucci, Massé-Biron, and Préfaut (2002) also conducted a study to assess the synergistic effects of cognitive and physical training. In this two-month study, participants were randomized to one of four groups. The four groups were an athletic training group (AT), a mental training group (MT), a combined athletic and mental training group (AMT), and a control group (C). The AT and AMT groups either walked or ran for 45 minutes twice a week at ventilatory threshold (VT). The MT and AMT groups attended one 90 minute session once a week that concentrated on learning eight themes. The control group met weekly to engage in leisure time activities such as painting and singing. The results for memory quotient were significantly improved for all three of the training groups. Furthermore, the AMT group had a significantly higher memory quotient than the three other groups. Thus, this study provides support for the hypothesis that combining PA and mental training can result in larger cognitive performance gains than either in isolation.

In summary, recent findings with rodents suggest that combining exercise and cognitively-engaging activities can improve brain structure and cognitive performance. Other studies combining exercise and cognitive training with dogs demonstrate long-term improvements in cognitive performance. Human studies also show that individuals who exercise and receive cognitive training have improvements in cognitive performance. Although these initial results are promising, studies testing the effects of combined PA and cognitive engagement with humans have not closely reflected what has been done with animals. In particular, the studies with animals typically involve the animals performing the cognitively-engaging activity simultaneously with exercise. It is possible that the simultaneous performance of the two activities will result in greater cognitive performance gains than performing either activity alone. Therefore, the purpose of this study is to investigate the effects of using a cognitively-engaging protocol during an exercise protocol, such that the cognitive training happens while the subject is exercising. Cognitive performance by participants in the combined group is expected to be better than either the cognitive training or exercise protocols alone.

Purpose

The purpose of this study was to combine exercise and cognitive training simultaneously to explore the effects on cognitive scores over time compared to exercise or cognitive training alone. The animal research shows that combining exercise and cognitive training produces gains in tissue density (Black, Isaacs, Anderson, Alcantara & Greenough, 1990) and performance in memory and learning tasks. (Lores-Arnaiz et al., 2006). Human research has shown that groups that exercise and receive some sort of cognitive training experience greater gains in performance on cognitive tasks (Fabre, Chamari, Mucci, Massé-Biron, & Préfaut, 2002; Small et al., 2006). However, these studies with humans have been limited because the research has concentrated on combining exercise with cognitive training in the same week or as a lifestyle change, not at the same time. Additionally, past research on chronic PA has focused almost exclusively on older adults and children, and research has not focused on the potential cognitive benefits of chronic PA for young adults. Lastly, Small et al. (2006) found cognitive benefits after a 14-day intervention, but research has not established if cognitive benefits can accrue after shorter interventions. Therefore, this study was designed to answer the following research question:

> Will a group that receives exercise and cognitive engagement simultaneously have greater improvements on cognitive measures from pretest to posttest as compared to groups that receive only exercise or only cognitive engagement?

CHAPTER II

LITERATURE REVIEW

There are two general paradigms that have been used to test the effects of exercise on cognition: acute and chronic. Acute exercise studies investigate the effects that a single bout of exercise has on cognitive performance. Chronic exercise studies investigate how long-term interventions impact cognitive performance. Both acute and chronic exercise studies have demonstrated a myriad of different effects on cognition.

Acute Exercise

Acute studies highlight how a single bout of exercise can improve cognitive function. These studies have varied in terms of whether cognitive performance has been measured shortly following the exercise bout or during exercise.

Kamijo et al. (2009) tested the effect of acute exercise on cognitive performance in younger (19 – 25 yrs) and older (60 – 75 yrs) adults. Participants underwent a light (30% VO_2max) or moderate (50 - 65% VO_2max) exercise intensity session followed by performance of a flanker task. The flanker task is a cognitive test that requires subjects to pay attention and respond to stimuli, such as an arrow on a screen, in both congruent and incongruent conditions. As each stimulus is presented the subjects are required to respond with the press of a button depending on the direction of the stimulus arrows. The stimulus arrows are surrounded on both sides by arrows either facing the same (congruent) or opposite (incongruent) directions. The task requires executive control to ignore irrelevant stimuli and select the correct response. During the flanker task each participant also wore an electroencephalogram (EEG) cap that measured brain electrical activity. The researchers found a significant decrease in RT following the moderate intensity exercise condition compared to the light exercise intensity condition for both age groups. In terms of brain activity, the moderate exercise condition resulted in larger P3 amplitude during performance of the flanker task, but only for the younger age group. Both age groups had shorter P3 latencies following the moderate and light exercise conditions as compared to baseline. P3 latency measures the amount of time that a participant evaluates a stimulus whereas a P3 amplitude is interpreted as indicative of the confidence subjects have that their answer is correct. Thus, these findings were interpreted as suggesting that exercise may facilitate quicker stimulus evaluation processes and more accurate response processes for both age groups.

Coles and Tomporowski (2008) investigated the acute effects of exercise on memory. All subjects completed three treatment conditions presented in a random counterbalanced order. The treatment conditions were: a rest condition, a control condition, and an exercise condition. The rest condition consisted of sitting alone in an adjacent room watching an educational documentary for 40 minutes. The control condition consisted of sitting at an exercise ergometer without pedaling. The exercise condition consisted of a 40 minute bout of cycling at a moderate intensity (60% VO_2max). Each subject underwent 3 cognitive testing trials that included the Brown-Peterson visual short term memory test, free-recall and delayed recall of a list of 40 words, and a set-switching element of executive performance. Their results showed nonsignificant improvements in the short-term and set-switching task following exercise. Interestingly, they found a significantly higher number of words recalled at the delayed recall for the exercise group. The researchers concluded that exercise enhances memory encoding of the information.

Sibley, Etnier, and Le Masurier (2006) explored the effects of a single session of exercise on performance on the Stroop test. College students (*n* = 76) were randomly assigned to an exercise or a control group. The exercise group performed 20 minutes of moderate intensity (60% VO_2max) exercise. The control group sat and read for 20 minutes. After either exercising or reading, the participants were asked to perform the Stroop test. The researchers found that successive attempts at the Stroop test significantly improved response speed due to learning. They also found that the exercise group performed significantly better on the interference test than the control group. The authors concluded that the significant results of improved performance on the color-word interference subtest suggest that exercise may improve executive function (EF).

More recently, Yaginasawa et al. (2010) used multichannel functional near-infrared spectroscopy (fNIRS) to view cortical activation while performing the Stroop interference (color-word) task before and after exercise or control conditions. The repeated measures design meant that 20 participants performed both conditions with the order of presentation of the conditions randomized and counterbalanced. In the exercise condition, participants exercised at 50% of their VO_2max on a cycle ergometer. In the control condition, the participants rested instead of exercising. The results showed a significant improvement on the Stroop task following the exercise condition when compared to the control condition. The results also showed that the exercise condition had a significantly higher amount of activity in the left dorsolateral prefrontal cortex for the Stroop interference task compared to the control. These findings could support the idea that exercise induces a change in the brain that may lead to enhanced executive function.

Davranche and Audiffen (2004) tested the effects of acute exercise on RT in 16 college athletes. Participants were asked to respond to a stimulus as accurately and quickly as possible by manipulating hand levers that were positioned at their sides. Participants performed 3 different exercise conditions of varying intensity in a random order: rest (no intensity), 20% (light) of VO_2 max, and 50% (moderate) of VO_2 max. Each day the participants practiced the choice RT task and performed a critical flicker fusion (CFF) task. CFF consisted of determining when a light emitting diode changed its flickering frequency. Each day of testing the participants practiced the tasks in the morning at rest to become familiar with the task. Then later in the afternoon the participants completed one of the 3 exercise conditions on the cycle ergometer while performing a choice RT task. The results showed that RT decreased as exercise intensity increased without a reduction in accuracy. These findings were significant in the moderate intensity condition, but did not reach significance in the light intensity. The results for the CFF task for the moderate condition were significantly more accurate than the rest condition. The findings thus suggest that acute moderate exercise facilitates cognitive performance in the choice RT task, and improved the subjects' ability to determine changes in the CFF task.

Davranche and McMorris (2009) conducted a study to investigate if cognitive control was affected by acute exercise. Sixteen participants (M = 32 yrs) performed cognitive tasks during two conditions that were presented in a counter balanced order. During the exercise condition, the participants cycled at their lactate threshold for 18 minutes. During the last 15 minutes of the condition they responded to a RT task. The other condition consisted of having the participants rest by sitting at the cycle ergometer and not pedaling. These participants also performed the RT task for 15 minutes. The RT task required that participants respond to different color circles that were presented on a computer screen. The color of the circle indicated which buttons the participants needed to select for a correct response. The results did not show a significant effect for accuracy, but did show a main effect for condition on RT with exercise resulting in faster RT than the rest condition. The authors concluded that exercise improved RT results without losing accuracy. Most importantly, the researchers found quicker RT for a task that was administered simultaneously with moderate exercise as compared to at rest.

Chronic Exercise Studies

Chronic exercise studies have been designed to identify the effects of long term exercise on cognitive performance. These studies fall into the broad categories of human studies and animal studies. Most of the work with humans has been focused on the effects of exercise training alone on cognitive outcomes. The animal studies, by contrast, have focused on exercise and cognitive training combined. As a result of the findings from these animal studies, recent research with humans has begun to combine the exercise along with the cognitive training to examine the potential synergistic effects on cognitive performance.

Exercise training alone in humans. Colcombe et al. (2004) conducted a six-month intervention study that investigated how increases in aerobic fitness for older adults (*n* = 29) could be associated with better cortical resources and cognitive performance on a flanker task. The subjects for this study had a mean age of 65 and were randomized to a control or an aerobic exercise group. The aerobic group met three times a week and engaged in up to 40 - 45 minutes of moderate and moderate-vigorous walking as determined from their VO_2max. The control group also met 3 times a week for the six month intervention, but during this time they only engaged in stretching, limbering, and toning. One week before and one week after the intervention, both groups had functional Magnetic Resonance Image (fMRI) scans taken. A fMRI scan is a way to look at blood flow and activity in the brain. During the fMRI scan, the participants underwent cognitive testing using a flanker task very similar to the one used by Kamijo et al. (2009) as previously described. After the 6 month intervention, the results showed that the aerobic group had significantly greater levels of task-related activity in the attentional control areas, along with a significantly reduced level of activity in the Anterior Cingulate Cortex (ACC). The ACC is a region associated with behavioral conflict, thus the reduction in blood flow observed for the aerobic group suggests less conflict with answering and more confidence in the correct choice. Results from the behavioral measures showed a significant reduction (11%) in behavioral conflict from time one to time two for the aerobic exercise group.

Hassmen and Kiovula (1997) conducted a study to determine if low intensity walking could influence cognitive performance, improve mental health, and improve working capacity. Older adults (*n* = 40; *M* = 66 yrs) were matched based on their sex, age, cognitive performance, and heart rate response to a cycle ergometer test. Then each matched pair had one person randomized to an exercise group and the other to a control group. The exercise group was assigned to regular walking at an RPE of 13 for 20 - 30 minutes three times a week for three months. The control group was given assignments to be performed three times a week at home. Unfortunately, the specific assignments were not explained in detail by the researchers, they were only called “mental tasks”. At the pretest and posttest, participants performed a set of cognitive and exercise tests. The cognitive tests consisted of a delayed word recall test, a face recognition test of 18 photographs, and three different computerized tasks from the Swedish Performance Evaluation System: a simple RT test, a choice RT test, and an eight digit span test. The exercise test was performed on a cycle ergometer at an intensity that resulted in an increase in HR to 120 BPM. The particular intensity needed to achieve this HR was used as a reference point for a moderate intensity. The researchers found significant performance improvements in the male exercise group in face recognition, that were not seen in the control groups or the female exercise group. The female exercise group significantly improved on digit span compared to the preliminary task. All four groups had an improved performance on the choice RT test. The follow-up exercise tests did not reveal a significant improvement in exercise performance or HR reactivity to exercise. The female control group had a decrease in performance in the face recognition test, the delayed recall test and the digit span test. The male control group had worse performance on the digit span test and the face recognition test. The authors concluded that the decrements in cognitive performance observed for the control groups over time were mitigated in the exercise group by the addition of a light to moderate exercise program 3 times a week.

Klusmann et al. (2010) investigated the beneficial impact of physical or mental activity on cognitive function in old age ($\geq$ 70 years old). Female participants (n = 250) were randomly assigned to one of three groups: exercise group, computer group, or control group. The control group was instructed not to alter their typical lifestyle. The exercise group attended a light intensity exercise training session three times a week for 30 minutes. The computer group completed multiple learning tasks that included memory tasks, learning how to operate software and hardware, playing/surfing/calculating/writing on the internet, emailing, drawing, videotaping and image editing. Before the subjects were informed of their treatment group, they participated in an extensive cognitive test battery. The test included the Consortium to Establish a Registry for Alzheimer's Disease (CERAD), Mini-Mental State Examination (MMSE), Naming semantic category members, Boston Naming Test, Figures Drawing, Word list Recall, Lector Test (educational level), LPS-3/50+ (tests fluid intelligence), Story recall test, Free and Cued Selective Reminding Test (FCSRT), Reitan Trail Making Tests (A & B), and the Stroop Test. This battery was applied at baseline and follow up to assess differences over time. The results indicated that both intervention groups had significant improvement in the delayed recall of the story, the free recall long delay, and working memory for the Trail

Making Test B/A. The control group scores did not significantly improve for any of the cognitive tests. In fact, there were significant decrements in performance on the FCSRT for the control group compared to the baseline score.

In sum, the literature suggests that chronic exercise has beneficial effects on cognitive performance. Some results reported improvements in performance on simple RT and choice RT. Other studies indicated that exercise might stave off the normal decline in cognitive performance that accompanies advancing age. Still other studies indicated that PA helped improve some aspects of cognition, such as delayed recall or working memory when compared to control groups.

Animal Models

Researchers are interested in understanding ways to increase the effect that a physical activity intervention has on cognitive performance. Animal research provides researchers with the opportunity to tightly control various aspects of the physical activity intervention which might ultimately have an impact on cognitive performance. In particular, a number of researchers have been interested in testing for differences between physical activity performed on a running wheel or a treadmill and physical activity performed in a more natural environment.

Black, Isaacs, Anderson, Alcantara and Greenough (1990) randomly assigned adult female rats (n = 38) into one of four different experimental conditions for 30 days. There was an acrobatic condition (AC) where the rats worked on progressively longer and more difficult trials of an elevated path. The path consisted of bridges, see-saws, balance beams and other obstacles. Each day they rats had to learn new obstacle paths.

The rats were encouraged by gentle physical encouragement and small chocolate-flavored rat chow. Researchers continued to add obstacles until they were completing 5 trials of 7 obstacles a day. This group experienced no more than 8.6 hours of motor learning training time for the study. In the forced exercise (FX) condition, rats were made to walk at a 10 meter per minute pace for progressively longer periods until they reached one hour of daily walking. Rats in a voluntary exercise (VX) group had access to a running wheel attached to their cage that recorded the number of rotations. Rats in an inactive condition (IC) were kept in a standard laboratory cage and had limited opportunities for learning or exercise. All rats were handled for one minute every day to control for any possible handling effects. The results showed that the acrobatic training group had a statistically significant (25%) increase in the number of synapses per Purkinje cell and a significantly higher molecular layer volume compared to the other three groups. The FX and VX conditions produced significantly higher blood vessel density than the AC or IC conditions. The researchers suggest that the increased synaptic activity of repetitive movement of the VX and FX groups created a greater metabolic load and therefore resulted in greater vasculature. The IC group did not have any significant increases in vessel density or connections. The authors concluded that the heightened cognitive engagement inherent in the AC resulted in increased cell density and the establishment of new connections and synapses.

Lores-Arnaiz et al. (2006) randomly assigned 27-month old rats to an enriched environmental condition or a control condition to look at changes to working memory (WM). WM in aged rats weakens over time. Both conditions received the same amount of light, food, and handling time. The enriched group had many cage furnishings such as a walkways, bridges, nests and toys. Every day five new and different objects were provided to every enriched cage for 24 hours. The control condition had only a water bottle and food cage. When the rats were only 90 days old, and they had 68 days of familiarization in their experimental conditions, the rats participated in spatial WM and long term memory (LTM) tasks. Tasks required animals to perform a maze task with eight arms and food at the end of 4 arms. The rats were trained to explore the eight arms and locate the food at the end of each arm. They were all given up to 10 minutes to explore the entire maze and find all 4 of the food treats. Then the rats did the WM task. The WM task had two phases. The first phase consisted of having 2 baited arms open where the rat could explore the maze for 5 minutes or until they found all of the food. Then 30 seconds later, phase two started. In phase two all of the maze arms were opened and the rats were able to explore the entire maze for 5 minutes. The researchers tracked the rats' movements and recorded which arm the rats entered. If the rat entered an arm that was open during phase one it was counted as a WM error because the food had already been eaten. If the rat entered into one of the non-baited arms from their training session from when they were 90 days old, then it was considered a LTM error. When the rats turned 27 months old, they were given a new training period and performed the same WM task protocol. Results showed that the rats in the enriched condition had significantly more days of one or fewer WM errors compared to the control condition. The enriched rats also had significantly greater increases in WM performance and significantly reduced time to complete phase two as compared to the standard caged rats.

This reduction in maze time occurred without a significant gain in errors, which suggests that the differences were not a function of speed, but rather was indicative of effects on learning.

Van Praag, Shubert, Zhao, and Gage (2005) looked at differences in sedentary and exercising mice. The typical median lifespan for the species was 26 months. For each activity level, there were both young (only 3 months old) and old (19 months old) mice. All four groups were housed individually and monitored behaviorally. The sedentary young and old groups did not have access to a running wheel, whereas the exercise groups had unrestricted access. All four groups had learning tested via the Morris Water Maze. The Morris Water Maze is a spatial learning task where rats swim until they find a hidden safety platform that is not moved from trial to trial. The performance outcomes were latency (the length of time it takes to find the platform), swim path (the total distance the rat swims from the start point to the platform), and a measure of target zone (the amount of time spent in each of the four quadrants of the maze). The intervention lasted 45 days. The results showed an interaction of exercise and age such that exercise had a differential effect on learning for the young compared to the aged mice. The old mice that did not exercise did not improve in their latency period or swim path. The aged exercise group experienced a significant reduction in latency and swim path that mimicked the young mice groups. This suggests that exercise could alleviate the detrimental effect that age has on cognition. Results also showed the young and old exercise groups spent significantly more time in the same quadrant of the maze in which the platform was located than did the aged sedentary group. This indicates that exercise could result in increases in spatial learning for young and old mice that leads to better performances on cognitive tasks. During the testing period, the mice were also given radioactive tracers to identify new cell growth in the brain. Both exercise groups had higher neuronal cell growth compared to the age matched sedentary controls. The young exercise group had the highest number of new neuronal cells. Interestingly, the old exercise group was not statistically different from the young sedentary group in terms of cell growth; thus suggesting that exercise may mediate the decline in cell growth that typically accompanies aging.

Milgram et al. (2005) investigated behavioral enrichment to prevent age-related cognitive declines in old (n = 48) and young (n = 17) beagle dogs for 9 months. The dogs were randomized into four groups with two treatment conditions. Group CC were given a control diet and a control experience. Group CE were given control food and an enriched experience. Group AC were given antioxidant and mitochondrial cofactor rich food and control experience. Group AE were given antioxidant and mitochondrial cofactor rich food and an enriched experience. The control food consisted of just 300 g of dog food that was identical to the test food, with the exception of the test food having both the added antioxidant and mitochondrial cofactors supplements. The dogs in the enriched groups received some cognitive measures and training. They learned a size discrimination task where they had to discern if two objects differed in size in order to earn a food reward. For example, the dog needed to select the smaller square for the treat. Then the dogs were taught to select the opposite size. The dogs were also trained to discriminate between black or white stimuli for a food reward. Upon successful understanding of the skill, they were taught to select the opposite color. Dogs in the controlled environment condition were housed in a pen either alone or with 1 kennel mate. They were given unlimited access to freshwater and handled exactly as the enriched dogs were. The dogs in the enriched condition also exercised twice a week in 15 minute intervals, were housed with 1- 3 kennel mates and were given a rotating set of toys that alternated weekly. The results showed that the enriched groups learned more accurately than the control groups. The enrichment groups also performed the black white task significantly better than the control group in the normal and reversal conditions.

Combined Exercise and Cognitive Training in Humans

Given the intriguing findings with animal studies suggesting that combining exercise and cognition could create larger effects in cognitive performance, it is important to investigate if this finding would also hold with humans. Several recent studies have begun to explore this possibility, however these studies fail to precisely replicate the designs used in the animal literature because the studies with humans have administered cognitive training and exercise at different times rather than simultaneously. Nonetheless, these few studies still highlight the possible positive effect seen in human models for combining exercise and cognitive training. Studies have also been conducted in which other forms of combined interventions have been implemented such as by combining PA with diet or with stress management training.

Masley, Weaver, Peri, and Phillips (2008) investigated how the addition of exercise, fiber, and stress management over the course of 10 weeks could promote better cognitive performance. Adults (*n* = 56) aged 21 - 65 years were randomly assigned to a control or treatment group. The treatment group met weekly to exercise at 70-85% max HR 5 to 6 days a week for 30 minutes and to strength train 3 days a week. They also had weekly nutrition and diet discussions and lectures as well as 10 - 20 minutes of each day for mentally calming activities like meditation or breathing activities. The control group was a no treatment control group, where in, they were instructed to continue the same activity level and diet for the duration of the study. Before and after the intervention, participants performed a cognitive test battery that included sections of the Stroop test, visual and verbal memory tests, symbol digit coding, shifting attention and continuous performance. Results showed statistically significant improvements compared to their baseline scores on reaction time, cognitive flexibility and mental speed for the treatment group.

Van Uffelen, Chinapaw, Mechelen and Hopman-Rock (2008) investigated how older adults (70 - 80 years) with mild cognitive impairment (MCI) could benefit from aerobic exercise and vitamin B supplementation. The year long study was a randomized control trial that included 152 community dwelling older individuals. The participants were randomly assigned to one of four different conditions that resulted from two levels of exercise and two levels of vitamin B. The exercise conditions were a twice-weekly moderate intensity group walking program or a twice weekly low intensity placebo activity program. The vitamin B levels were a daily placebo pill or a pill with vitamins B-12 (0.4mg), B-6 (50mg) and folic acid (5mg). Cognitive measures were taken at baseline, 6 months, and 12 months. The group that received the walking and the vitamin supplementation did not have any significant changes. However, the results for the walking group showed improvements in memory for the men and improvements in both memory and attention in the women. The participants who showed up to 75% of the sessions had larger improvements in their cognitive scores compared to baseline, suggesting that there was a link between physical activity participation and cognitive gains. Based upon their results, the authors concluded the walking program was successful in improving memory for men and women, and attention for women who attended more physical activity sessions.

Only two published studies report on the effects of combined cognitive and physical activity programs on cognitive performance. Small et al. (2006) investigated the effects of a 14-day longevity lifestyle program on brain function and cognition. Adults ($n = 17$) aged 35-69 were randomized to an intervention or a control group. Adults in the control group were asked to continue their usual lifestyle habits during the two weeks between baseline and follow-up procedures. Adults in the intervention group were given a notebook with detailed instructions and daily exercises for healthy lifestyle strategies. Some of the strategies included memory training, relaxation techniques, diet information, and physical conditioning. Daily exercises (brain teasers and mind puzzles) were also accompanied with memory strategies, visualization techniques, focus skills, and mnemonic techniques. Brisk walks (30-45minutes) and other physical training were recommended daily for improved cerebrovascular health. Diet information included menus and shopping lists that included antioxidant and omega 3 rich foods. Screening for both groups at baseline and follow-up included the Mini-Mental State Examination (MMSE) and the Hamilton Rating for Depression. Cognitive tests included a multitrial verbal learning and memory test, the Memory Functioning Questionnaire (MFQ) and a word generation test. Positron Emission Tomography (PET) and brain magnetic resonance imaging (MRI) scans were taken at baseline and follow up for both groups as well. Results showed that the intervention group significantly improved on the verbal fluency from the baseline measure whereas the control group did not change from baseline. Imaging results showed that the intervention group had a 5% significant reduction in left dorsolateral prefrontal activation from baseline and when compared to the control group activity. The control group did not have any significant changes from baseline. The left dorsolateral prefrontal cortex is associated with anxiety symptoms and verbal fluency. The reduction in brain activation could be a result of less anxiety and an improved cognitive efficiency. One of the major shortcomings of this study was that the researchers did not record or control the participant's behavior. They did not receive a measure of physical activity, diet, or what cognitive activities the participants completed.

Fabre, Chamari, Mucci, Massé-Biron, and Préfaut (2002) conducted a two month study with thirty-two elderly adults (60-76 years old). They were randomly assigned to one of four groups. The four groups were an athletic training group (AT), a mental training group (MT), a combined athletic and mental training group (AMT), and a control group(C). The AT and AMT group went to supervised sessions of walking and running for 45 minutes following a 5 minute warm up and a ten minute cool down twice a week for two months. The exercise intensity was either a brisk walk or jogging at ventilatory threshold (VT). VT is the point at which ventilation increases without an equal increase in oxygen uptake. The body must start to use anaerobic means to meet the demands of the exercise. The mental training group attended one 90 minute session once a week that concentrated on learning eight themes. The cognitive variables were measured using the Wechsler memory scale and the BEC 96. The Wechsler involves eight different subtests: general information, orientation, mental control, logical memory-immediate recall, digit span in order and reverse order, visual reproductions, and paired associates learning. When all the subtests are added they provide a memory quotient. The BEC 96 has eight subtests: recall, learning, orientation, manipulation, mental problems, verbal fluency, denomination, and visual reproduction. A low score on any subtest indicates a mental impairment. These two cognitive tests were given before and after the training period to assess changes. At the end of the training session, the results showed no significant differences in the control group for the cognitive variables. The results for memory quotient were significantly improved for all three of the trained groups. The group that had athletic training and cognitive training had a significantly higher memory quotient than the three other groups.

In a study that is not yet completed, another group of researchers are testing the effects of combined exercise and cognitive training. In an on-going study with older adults (65 - 75), O'Dwyer et al. (2007) randomly assigned individuals (n = 99) to one of three groups for sixteen weeks. One exercise only group met three times a week for 60 minutes and included aerobic and strength training exercises. Another group received two days of the exercise session and one day of cognitive training per week. The cognitive training consisted of three modules (memory, EF, and mental speed). The final group was a control group that did not receive any treatment. Before and after the 16 weeks, many different cognitive tests will be given to look at mental speed, EF, and memory. A few examples of the cognitive testing included: the Stroop test, a RT test, a sorting test, and a choice RT test to name a few. Results from this study are not yet published, but this study is indicative of the current interest in considering that the beneficial effects of exercise could be enhanced by combining exercise training and cognitive training.

Summary

Given that animal research clearly supports the possibility that larger cognitive performance gains may result from programs that combine physical activity with cognitive training, the purpose of this study is to investigate the effects of a combined exercise and cognitive training program on subsequent cognitive performance. It is anticipated that exercise and cognitive training will have a synergistic effect on cognitive performance. That is, when the two are combined, they will produce better performance than either exercise or cognitive training alone could produce. Based on past evidence I expect that the reason for the lack of strong evidence supporting this hypothesis with human studies is because the correct combination of exercise and cognitive training has not been used. Previous studies with humans have tried to replicate the enriched environment settings that are seen in the long term animal studies. However, most of these do not successfully “replicate” the variables for humans. Subjects are asked to participate in cognitive training additionally or as part of the weekly exercise regimen. Instead to better follow the animal literature, there needs to be studies on the effect of learning during exercise. While the subjects are walking or biking they could be engaged in the cognitive activity. This is what the mice were experiencing when they were navigating a new tunnel, or playing with an engaging toy that also increases energy expenditure. Thus, refocusing the research to truly combine the cognitively-engaging activity with the physical activity intervention is the next logical step to mimic the findings in the animal literature. In doing so, I think we will find greater gains in cognitive performance than exercise or cognition could do alone. Therefore, it is important to investigate the effects of combined cognitive activities and exercise performed simultaneously on cognitive performance to further the field of exercise and cognition.

CHAPTER III

METHODS

Subjects

Students (*N* = 24) from the University of North Carolina at Greensboro were recruited from classes in the kinesiology department during the 2010-2011 school year. Power analyses indicated that a sample size of 24 (8 per group) would allow the detection of a moderate effect size ($d = .6$; $p < .05$). Subjects were between the ages of 18 and 35 and were deemed healthy enough to exercise with the American Heart Association (AHA)/American College of Sports Medicine (ACSM) Health/Fitness Facility Preparticipation Screening Questionnaire (Balady et al., 1998). The health survey is specifically designed to identify individuals who may not be healthy enough to exercise by asking questions about the subjects' heart health, symptoms during exercise, family history, and other possible health issues. The survey was administered by the researcher and consisted of roughly 20 yes/no questions.

Study Design

A randomized, within-between experimental design was used to collect quantitative data. The within-subject factor was the change in cognitive function induced by cognitive training. The between-subject factor was the average change in group score on cognitive function. Subjects were randomized to one of three groups: group one was exercise only (bike), group two was cognitively train only (game), and group three was exercise while cognitively training (both). All groups completed cognitive tests on days one and eight, but the protocol on days two through seven were different depending on the group. All testing was done in the Sport and Exercise Psychology Lab in the Health and Human Performance Building room 247 at the University of North Carolina at Greensboro in Greensboro NC.

Treatment groups. Testing and training for each subject occurred within the same one-hour block for each visit. Participants came in on a Monday – Wednesday – Friday or a Tuesday – Thursday – Saturday schedule. On day one subjects entered the lab and were asked to complete the informed consent, a demographics form, the AHA/ACSM preparticipation health readiness questionnaire, and the NHANES exercise and PA assessment. Upon completion of the forms, subjects entered the testing room 247a where they were instructed that they would receive 4 cognitive tests. In a randomized and counter balanced order, the subjects were given the Stroop Test, the Trail Making Test, the Wonderlic Personnel Test, and the Paced Auditory Serial Addition Test (PASAT). On day 8 all participants completed each test again in a randomized and counterbalanced order. On days 2 - 7 subjects entered the lab, put on a Polar heart rate (HR) monitor, and were instructed to sit for 5 minutes on the exercise bike to get an estimate of resting HR. Participants then performed the assigned treatment condition.

Bike group. On days two through seven, after putting on the HR monitor, the EX group was instructed to pedal at a minimum of 60 RPM for 30 minutes at a moderate intensity. For the first 5 minutes the bike group pedaled while the resistance was increased every minute until the participant reached a HR corresponding to the ACSM guideline for moderate intensity (64-76% of age-predicted HR max). Intensity was monitored by the Polar HR monitor, which was programmed to beep if the participant's HR was not within the 64-76% range. Predicted HR max was estimated from the 220-age equation. Resistance was individualized in Watts by the experimenter for each participant and adjusted on day two to ensure that the subject was working at a moderate intensity. The lab was also equipped with a timer that beeped at the 27th minute to signify a cool down period. Subjects were instructed to begin a cool down period at this time. Resistance was also reduced to 15 - 25 Watts during this final 3 minutes of exercise. After the 30 minutes subjects were once again thanked for their participation and reminded of their next session.

Game group. Participants in the game group also wore a HR monitor and sat on the Lode exercise bike during the 30 minute session. After baseline measures of HR, subjects waited 5 minutes so that the time working with the game was the same for the game and both group. After these 5 minutes, the subjects were given the Nintendo DS with the BrainAge software. The software had multiple games that the subject could select. The subject was instructed to play all games in the training mode once and then if there was time they could play other games again. Participants could play the games in any order, but they had to play at least one math game per day. On days two through seven they were instructed to play the game continuously from minutes 5 to 27. When the timer went off at the three minute mark, subjects were instructed to hand the DS system back to the experimenter. They then sat quietly for the final three minutes on the bike.

After the subjects completed their training for the day, they were thanked for their participation and reminded of the time for their next training session.

Both group. On days 2-7 the both group sat on the exercise bike wearing a HR monitor for 5 minutes to establish resting HR. They were then instructed to perform a 5 minute warm-up just like the bike group. After the 5 minute warm-up they were given the Nintendo DS and the BrainAge 2 software with the same instructions as the game group. They were then told to bike and play the game until the 3 minute warning for cool-down sounded. Then they were instructed to turn off the game and cool down just as the bike group. They were then thanked and reminded of their next training session.

Variables and Measures

The dependent variable for this study was executive function (EF). The instruments that were used to assess EF were the Wonderlic Personnel Test (WPT), the Paced Auditory Serial Addition Test (PASAT), the Stroop Test, and the Trail Making Test.

Demographic data. Subjects were men and women between the ages of 18 to 35 years of age. Participants' history of experience with the cognitive training software was recorded, as was information on other activities typically performed during exercise (e.g., watching TV, texting, reading).

Physical activity. The National Health and Nutrition Examination Survey (NHANES) is a survey created by the Center for Disease Control (CDC) that provided data on the subjects' exercise patterns for the previous two weeks. The NHANES was utilized as a screening tool to classify subjects into exercise categories depending on their reported amounts.

Cognitive measures. The Wonderlic Personnel Test (WPT), is a 12-minute test that assesses fluid and crystallized Intelligence Quotient (IQ). Crystallized IQ refers to how well a person can use language based information, such as vocabulary or scientific principles. Fluid IQ reflects how well a person can respond to a new task, like interpreting patterns or drawing inference from a new situation. The WPT does not distinguish between fluid and crystallized IQ, but because the researcher was not concerned with looking at either IQ specifically, the WPT was used to provide a good measure of overall daily cognitive functioning. In addition, the WPT has been found to have very strong metrics. Internal consistency, alternate forms consistency and test-retest reliability all have had strong ranges of .88 to .94, .73 to .95, and .82 to .94 respectively (Wonderlic, 1992). The WPT was scored using the provided answer key that produced a number score and a higher score on the WPT indicates better performance.

The paced auditory serial addition test. The PASAT (Sampson, 1956) is a recorded list of digits that was played to the subject. The digits were given at four regular time intervals of increasing speed (2.4, 2.0, 1.6, and 1.2 seconds). The subject answered aloud the sum of the previous number with the new number. This measure assesses working memory, processing speed, attention, and mathematical ability. In combination, these test scores equate to a good estimate of EF. Construct validity reports have shown the PASAT to be highly correlated with attention and conceptual ability as well as EF (O'Donnell, MacGregor, Dabrowski, Oestreicher & Romero, 1994). Tombaugh (2006) reported adequate psychometric properties of internal consistency and test–retest reliability. However, the test is susceptible to practice effects. For the current study, practice effects were of little concern because all of the subjects, regardless of treatment condition, took the PASAT twice. Since everyone presumably experienced practice effects, any observable differences between the groups could then be attributed to treatment effects. The PASAT was scored in both the traditional method (Levin, n.d.) and in a modified method (Lezak, Howieson, & Loring, 2004). Using the traditional fashion, the total number of correct sums provided was the measure of performance for each speed. Using the modified fashion, sums were only counted as correct if they were immediately followed by a correct sum. For example, in a set if the participant gave one incorrect response then gave two correct responses then missed another response they would have only scored 1 point using the modified method.

Stroop test. The Stroop Test (Stroop, 1935) is a task that required the participant to use attention, memory and task switching. The Stroop Test consists of three different tests. For each test the individual read stimuli aloud to the experimenter. During the first test (the word test) the stimuli consisted of three color names (red, blue, green) written in a random order in black ink. Participants were asked to read through the list of words as fast as they were able. The second test was a color test and the stimuli consisted of squares that were in one of three different colors (red, blue, green). For the color test, participants indicated the color of the ink of the squares as quickly as possible. Both the word test and the color test are considered measures of information-processing speed. The third and final test was an inhibition test. In this test the stimuli were the same color words from the first test (red, blue, green) written in a different color ink (red, blue, or green) that did not match the word. For example the word could be “blue” but be written in red ink. Participants were asked to name the color of the ink and not read the word. This test assessed how well a participant could ignore the irrelevant stimuli (the written word), and pay attention to the important information (color of the ink). Test-retest reliability has previously been reported as high as .84 and .86 for the color test and the inhibition test respectively (Siegrist, 1997). For all tests, the measure of performance was the length of time it took the participant to identify all of the stimuli provided (n = 50). Thus, a higher score was indicative of slower performance. The Stroop interference score was calculated by subtracting the average of the word subtest and the color subtest from the color-word subtest. The resulting score removed reading and color processing time, leaving only interference processing time and, again, a higher score was indicative of a slower performance.

Trail making test. For the Trail Making Test A, participants were given a page that had numbers 1 – 25 presented in random order. Participants were asked to draw a line with a pencil to connect the numbers. They were asked to connect the numbers by counting from 1 – 25. Participants were timed to completion in seconds. A higher score indicated a slower performance. For the Trail Making Test B participants were given a sheet of paper that had the numbers 1-12 and letters A-M on the page. The experimenter asked the participants to use a pencil to draw a line in ascending order while alternating between the lists. They drew a line from 1 to A to 2 to B to 3 to C and so on in that order. Participants were timed until they completed the task. Thus a higher score indicated a slower performance. This test was a measure of working memory and set-shifting in EF. Working memory was defined as the participant's ability to attend to two different stimuli as they alternated from numbers to letters and to be able to remember where they were going next. Set-shifting comes from one's ability to move fluidly between the number and letter set until the task was completed (Soukup, Ingram, Grady, & Schiess, 1998). The TMT B task involved counting by switching between numbers and letters (1, a, 2, b, 3, c, etc.) The TMT A task only involved counting in numbers. Both tasks had the same amount of items (*n* = 25) and performance was scored as the time to complete the page. The difference in completion time between the TMT A and the TMT B provided a value known at the set-switch score or, the time it took for a person to switch between sets (i. e. letters and numbers). Higher set-switch scores were indicative of slower performance.

Cognitive software. BrainAge 2 on the Nintendo DS is a hand held interactive software program that provides a fun way to engage oneself in learning. The subject was presented with a host of different problem-solving situations. The first task was the "sign finder", which presented randomized mathematical problems with the sign of the equation removed (2 □ 8 = 10). The subject was required to answer by writing in the correct arithmetic sign to complete the problem and produce the correct answer. The problems consisted of addition, subtraction, multiplication and division. The "piano player" presented a small piano that required subjects to play the correct note at the correct time to keep the song playing in real time. "Word scramble" presented subjects with a rotating set of letters and required subjects to spell out a common word. The words got progressively longer and the letters that were spinning were arranged in random order. “Memory sprint” involved tracking a person in a race as they passed and were passed by other racers. At the end of the race, they were required to write in the runner’s finishing place. The speed of the race gradually increased. The number of other racers that passed the target person also changed to increase difficulty. “Change maker” presented the person with a starting dollar amount and asked them to make change depending on the final price. They could combine different coins in different orders to get the correct change. “Word blend” featured three different voices saying different words at the same time. The participant was familiarized with the voice that they were to attend to and was told to ignore the irrelevant voice(s) and write down each of the words that were spoken. The words became more difficult and the number of voices increased. For “Calendar count”, participants used math skills to answer questions to provide the correct date. For example, the prompt would say “What day of the week will it be 1 day after today?” In “Math Recall”, subjects performed calculations as they remembered the number that was crossed out. Much like a visual representation of the PASAT, the subject was presented with two numbers and asked to add them together. Then, one of the two numbers was erased and the subject had to write in the sum of the numbers. Then a new number arrived and the old number was covered up. This forced the subject to use working memory to remember the last number that was shown to complete the new math problem. “Clock spin” presented a clock on one screen that was rotated. The clock could be upside down, right side up or any of the other possible combinations between the two orientations. The subject answered the hours and minutes displayed on the clock. The clock switched between analogue and digital outputs. “Block count” presented the subject with a picture of letters arranged into columns. Part of the picture was covered up as blocks fell into different columns at different heights. The subject had to remember the number of blocks in each column and responded with the correct height of each column. The number of columns and rate at which the boxes fell increased as time continued.

These tasks included pattern recognition, working memory, everyday cognitive skills (such as estimating time), word/math puzzles, inhibition, and planning. The scores from each game have not validated with any psychological construct and have not been tested to see if they correlate with any measure of cognitive performance. However, the software delivered an interactive learning program with randomized questions that focused on challenging the subject. It was also very portable and light so that the subject did not have any difficulty holding the handheld Nintendo while exercising on the stationary cycle. This software was intended to be used like any cognitive training tool such as math or vocabulary flashcards.

Data Analysis

Descriptive data, such as the means and standard deviations of the demographic data, and cognitive tests were recorded. All demographic data were coded and entered into SPSS statistical software to check for inconsistencies in baseline values of the groups. A 3 (Treatment Groups: both, game, bike) x 2 (Time: Baseline and Post-test) x Test (Stroop = 3 subtests, TMT = 2 subtests, PASAT = 4 subtests) repeated measures ANOVA was conducted to look for differences in cognitive test performance (WPT, Stroop test, Trail Making test, PASAT). Significant omNibus tests were followed up with appropriate univariate follow-up tests.

Sphericity. For all repeated measures analyses, Mauchly’s test of sphericity was utilized to ensure the sphericity assumption had been met. If it was not met, a Huynh-Feldt adjustment was used for degrees of freedom.

CHAPTER IV

RESULTS

Participant Information

Age and education. Twenty-six college-aged participants were recruited for this study. Due to complications with adherence to the study, two participants had to be removed. All other participants completed the 8-day study leaving a total of 24 (10 men, 14 women) participants. The average age of the sample was 21.79 (*SD* = 3.28) years. The participants had an average of 15.52 (*SD* = 2.1) years of education. Most of the participants (*n* = 18) were currently working on the Bachelors degree while the other participants were working on their graduate degree (5 M.S., 1 PhD.)

Exercise history. Participants engaged in moderate intensity exercise for 77.40 (*SD* = 81.05) minutes per day and 4.43 (*SD* = 1.41) days per week. The NHANES average for all participants was 5.76 (*SD* = 4.89) (Kcal/Kg)/Day. Descriptive information for the sample is provided in Table 1. Almost all (*n* = 22) of the participants indicated that they engaged in aerobic or cardio exercise primarily, while only 2 indicated that their primary means of exercise were resistance or anaerobic training instead of aerobic. The majority (*n* = 17) of the participants indicated they were typically cognitively engaged during exercise (listening to music, watching TV, reading, etc.).

Table 1.

Participant Demographics by Group

Group	Age (years)	Yrs of Edu	NHANES[a]	Exercise Duration	
				Days/Week	Min/Day
Bike	21.750	16.125[c]	5.070	4.000	68.438
Game	22.250	16.375[c]	6.471	4.500	66.250
Both[b]	20.375	14.063	5.748	4.313	97.500

Note: [a] Participants were asked to answer questions based on exercise they had completed in the last 14 days. NHANES is measured in (Kcal/Kg)/Day.
[b] Both – The group that completed the exercise intervention while performing the learning software simultaneously.
[c] Significantly different from Both, $p < .05$.
Yrs of Edu = Years of Education, NHANES = National Health and Nutrition Examination Survey.

Cognitive engagement background. A one-way ANOVA to test years of education found a significant difference between groups, $F(2, 21) = 3.56$, $p = 0.047$, partial $\eta^2 = .253$, with participants in the bike and game groups being more well educated than those in the both group. None of the participants had ever owned or played a Nintendo DS. Seventeen of the participants owned a smartphone during the time of the study. Of those, sixteen indicated that they used their phone very often (more than once per hour) for email, texting, games, and phone calls. All participants were asked if they engaged in extracurricular intellectually stimulating activities such as IQ tests or learning software (Sudoku, word puzzles, etc) done outside of class. Responses ranged from never to very often and did not significantly differ between the groups, $F(2, 21) = .781$, $p > .05$.

Completed exercise. A one-way ANOVA to check for significant differences between the distance travelled in kilometers for the two groups that exercised showed no significant differences $F(1, 15) = 2.003$, $p = .179$, partial $\eta^2 = 0.125$. The means (standard deviations) for the bike group and the both group were 10.55 (2.88) and 8.8 (1.99) km, respectively.

Cognitive Measures

Wonderlic personnel test. The results of the 2-way RM ANOVA for the Wonderlic test indicated that the main effect for time was significant, $F(1, 21) = 12.531$, $p = .002$, partial $\eta^2 = 0.374$. Means indicated that performance increased from pretest ($M = 21.83$, $SD = 4.88$) to post-test ($M = 24.21$, $SD = 4.69$) for all groups. Table 2 shows the means and standard deviations for the individual groups. The tests for a main effect of group was not significant $F(2, 20) = 1.485$, $p = .249$, partial $\eta^2 = 0.124$. There was no significant interaction of time x group, $F(2, 21) = .220$, $p = .804$, partial $\eta^2 = 0.021$.

Stroop test. One participant was removed from the Stroop test and the PASAT analyses because scores on these measures were uncharacteristic of the rest of the sample. While the Stroop performance worsened from pretest to posttest the improvement in PASAT was three times greater than the rest of the sample. After that outlier was removed, the results of the 3-way RM ANOVA for the Stroop test indicated that the main effect for time was significant, $F(1, 20) = 19.51$, $p < .001$, partial $\eta^2 = 0.494$. Means indicated that participants reduced their time from pretest ($M = 27.18$, $SE = .92$) to posttest (*M* = 25.10, *SE* = 1.08). The main effect for test was also significant, $F(2, 19)$ = 54.84, $p < .001$, partial $\eta^2 = 0.852$. These means show completion time for the word (*M* = 20.65, *SE* = .694) and color (*M* = 23.35, *SE* = .992) tests were faster than for the color-word (*M* = 34.41, *SE* = 1.64) test. The main effect for group was not significant, $F(2, 20)$ = .097, $p = .908$, partial $\eta^2 = 0.01$. There was no significant interaction of time x group, $F(2, 20) = 2.045$, $p = .156$, partial $\eta^2 = 0.170$, or test x group, $F(4, 40) = .686$, $p = .606$, partial $\eta^2 = 0.064$. However, there was a significant interaction of time x test, $F(2, 19)$ = 3.70, $p = .034$, partial $\eta^2 = 0.156$. Examination of the means indicated that scores decreased from pretest to posttest for all tests over time; however, the decrease in performance was greatest for the color-word test (see Figure 1). There was also a significant interaction of time x test x group, $F(4, 40) = 3.02$, $p = .029$, partial $\eta^2 = 0.232$ (see Figure 2). Results indicated that the bike group and the both group improved from pretest to posttest on all three tests. However, the game group only improved on the color test and remained essentially stable in their performance on the word and color-word tests. Means and standard deviations by group and subtest are presented in Table 3.

Stroop interference test. Means and standard deviations for each group are provided in Table 4. A 2-way RM ANOVA showed a significant effect for time, $F(1, 20)$ = 4.74, $p = .042$, partial $\eta^2 = 0.192$. Means indicated that participants improved their processing time from pretest (*M* = 13.30, *SE* = .997) to posttest (*M* = 11.52, *SE* = 1.43). There was no significant main effect for group $F(2, 20) = .454$, $p = .641$, partial η^2 = .043. There was a significant time x group interaction, $F(2, 20) = 3.91$, $p = .037$, partial $\eta^2 = 0.281$. Examination of the means (see Figure 3) indicated that the bike group and the both group improved their time to completion from pretest to posttest. In contrast, the game group had an increase in the interference score from pretest to posttest.

Trail making tests. The results of the 3-way RM ANOVA for the TMT indicated that the main effect for test was significant, $F(1, 21) = 174.20, p < .001$, partial $\eta^2 = 0.89$. An examination of the means showed that performance on the TMT B ($M = 53.32$, $SE = 2.61$) took significantly longer than performance on the TMT A ($M = 26.22$, $SE = 1.57$). The main effect for time was significant, $F(1, 21) = 38.37, p < .001$, partial $\eta^2 = 0.65$. Participants reduced their time to completion from pretest ($M = 43.09$, $SE = 2.08$) to posttest ($M = 36.45$, $SE = 1.85$). The main effect for group was not significant, $F(2, 21) = 2.01, p = .147$, partial $\eta^2 = .167$. Additionally, there were no significant interactions of time x group, $F(2, 21) = .77, p = .476$, partial $\eta^2 = 0.068$, test x group $F(2, 21) = .82, p = .454$, partial $\eta^2 = 0.072$, time x test $F(1, 21) = .983, p = .333$, partial $\eta^2 = 0.045$, or time x test x group $F(2, 21) = 1.96, p = .165$, partial $\eta^2 = 0.158$. Means and standard deviations for each group at all time points are reported in Table 5.

Set-switch score. A 2-way RM ANOVA indicated the main effect for time was not significant, $F(2, 20) = 2.59, p = .123$, partial $\eta^2 = 0.115$. The main effect for group was not significant $F(2, 20) = .683, p = .516$, partial $\eta^2 = 0.064$. The interaction of time x group approached significance, $F(2, 20) = 3.21, p = .063$, partial $\eta^2 = 0.242$. Examination of the means (see Figure 4) indicated that the bike group and the both group reduced their set-switch score from pretest to posttest. In contrast, the game group increased their set-switch score from pretest to posttest. The means are presented in Table 6.

PASAT traditional scoring. The results of the 3-way RM ANOVA for the PASAT indicated that the main effect for time was significant, $F(1, 21) = 42.52$, $p < .001$, partial $\eta^2 = 0.68$. Means indicated that participants improved their scores from pretest (*M* = 31.62, *SE* = 1.86) to posttest (*M* = 36.68, *SE* = 1.91). The main effect for difficulty was significant, $F(3, 18) = 111.16$, $p < .001$, partial $\eta^2 = 0.949$. Examination of the means showed that total number correct decreased as difficulty increased (2.4” spacing *M* = 43.81, *SE* = 1.81; 2.0” spacing *M* = 38.57, *SE* = 1.86; 1.6” spacing *M* = 32.80, *SE* = 2.28; 1.2” spacing *M* = 21.42, *SE* = 1.85). The main effect for group approached significance, $F(2, 20) = 3.04$, $p = .071$, partial $\eta^2 = .262$, with means indicating that the bike group (*M* = 40.73, *SE* = 3.34) had higher scores compared to the both (*M* = 30.89, *SE* = 3.13) and game (*M* = 30.83, *SE* = 3.13) groups. However, there was no significant interaction for time x group $F(2, 20) = .867$, $p = .435$, partial $\eta^2 = 0.08$, difficulty x group, $F(6, 38) = 1.20$, $p = .375$, partial $\eta^2 = 0.10$, or time x difficulty x group, $F(6, 38) = .708$, $p = .64$, partial $\eta^2 = 0.07$. There was a significant interaction of time x difficulty, $F(2.81, 56.12) = 3.40$, $p = .026$, partial $\eta^2 = 0.145$, Examination of the means indicated that test scores improved on each difficulty level from pretest to posttest. The 2.4” spacing had the largest increase in scores, followed by the 1.6” spacing, then the 2.0” spacing, then the 1.2” spacing (see Figure 5).

PASAT Lezak recommended scoring. The results of the 3-way RM ANOVA for the rescored PASAT indicated that the main effect for time was significant, $F(1,20) = 26.50$, $p < .001$, partial $\eta^2 = 0.570$, with means indicating that participants improved their scores from pretest (*M* = 18.40, *SE* = 1.95) to posttest (*M* = 25.20, *SE* = 2.38). The main effect for group was not significant, $F(2, 21) = 1.35$, $p = .282$, partial $\eta^2 = 0.119$. The main effect for difficulty was significant, $F(3, 19) = 111.82$, $p < .001$, partial $\eta^2 = 0.848$. Examination of the means indicated that participants had fewer correct responses as difficulty level increased (2.4" spacing $M = 33.72$, $SE = 2.55$; 2.0" spacing $M = 25.43$, $SE = 2.38$; 1.6" spacing $M = 19.97$, $SE = 2.44$; 1.2" spacing $M = 8.07$, $SE = 1.47$). The interaction of time x difficulty approached significance, $F(2.672, 53.44) = 2.49$, $p = .077$, partial $\eta^2 = 0.111$. Examination of the means showed the 2.4" spacing had the largest increase in scores over time followed by the 1.6" spacing, then the 2.0" spacing, then the 1.2" spacing (see Figure 6). The interaction for difficulty x group approached significance $F(5.93, 59.29) = 2.25$, $p = .051$, partial $\eta^2 = 0.184$. Examination of the means showed that the bike group had the most correct responses for all difficulty levels, followed by the game group, then the both group (see Figure 7). The interaction effects were not significant for time x group $F(2, 20) = .075$, $p = .928$, partial $\eta^2 = .007$, or time x difficulty x group $F(6, 40) = .888$, $p = .509$, partial $\eta^2 = 0.082$. Means for both types of scoring are shown in Table 7.

CHAPTER V

DISCUSSION

Meta analytic reviews suggest that chronic exercise has beneficial effects on cognitive performance. Chronic exercise interventions show small effects on cognitive performance for the general population (Etnier et al., 1997). Small effects are also observed in studies with children (Sibley & Etnier, 2003). Studies with older adults show moderate effects are observed for older populations (Angevaren et al., 2008; Colcombe & Kramer, 2003; Heyn et al., 2004). Other studies indicate that exercise might delay or inhibit the normal decline in cognitive performance that accompanies advancing age (Salthouse, 2003).

The purpose of this study was to combine exercise and cognitive training simultaneously to examine the effects on cognitive scores as compared to exercise or cognitive training alone. To test this question, participants were randomly assigned to one of three intervention groups: a biking only group, a cognitive training only group, and a combined group. They were tested on three measures of EF (TMT A/B, PASAT, and Stroop) and a measure of crystallized and fluid intelligence (Wonderlic) before and after the intervention.

With the exception of the TMT set-switch score, a significant main effect for time was observed for all measures and indicated that performance improved on every measure from pretest to posttest. This was expected, as all of the measures are susceptible to practice effects. However, because participants were randomly assigned to treatment conditions and all participants performed both the pretest and the posttest, one can assume that the participants experienced the same amount of practice effects regardless of group. Therefore, any differences in the amount of change in performance by group can be attributed to the intervention received.

The results indicated that there was a significant interaction of time x test x group for the Stroop test. This finding provides further clarification of the nature of the effect of treatment condition on Stroop performance gains. Results indicated that over time, the groups' change in performance from pretest to posttest was different across the Stroop tests. Specifically, the game group only improved on the color test overtime, but remained relatively stable in performance on the other two tests. The both group and the bike group improved on all three tests. The Stroop color and word tests are both considered measures of information processing. Thus, these results indicate that all groups improved their speed of information-processing from pretest to posttest. Performance on the Stroop color-word test is considered a measure of inhibition, shifting, and selective attention (Chang & Etnier, 2009b). Thus, these findings further suggest that a 6-session physical activity program improves these cognitive abilities.

These findings were further explored by assessing the effects of time and group on the measure of Stroop interference. The interference score is calculated from the three Stroop tests, so it is not surprising that the results from this test would reflect the previously described findings on the individual tests. The Stroop interference score factors out the speed of reading and color naming, thus only measuring the time it takes to inhibit the dominant response (reading a word) and say the non-dominant response (name the color ink). Results indicated that there was a significant time x group interaction for the Stroop interference test. This interference score provides a measure of executive function and is specifically related to inhibition, set-shifting, and selective attention (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). The results showed that the both group and the bike group improved from pretest to posttest. The game group actually increased their time from pretest to posttest indicating that their performance declined. These findings support past research, which has found that physical activity has a positive effect on EF (Etnier & Chang, 2009), but extends the literature by demonstrating that the effect can be observed in college-aged individuals and after a short-term physical activity intervention. Further, the results suggest that the improvements in performance on this task were greater for the both group than the other two groups, suggesting that pairing exercise with cognitive training may have a positive impact on EF.

The TMT set-switch score is a measure of cognitive control which is a category of EF (Arbuthnott & Frank, 2000). For the TMT set-switch score, the interaction of time x group approached significance ($p = .068$) and indicated that both exercise intervention groups improved from pretest to posttest, whereas the game group again experienced a decrease in performance. Again, these improvements are consistent with past research (Chang & Etnier, 2009a) that has shown exercise has a positive effect on cognitive measures. The decline in performance experienced by the game group suggests that they had a reduction in ability to switch from one category to another. This could be related to the attention that the game requires. It might be that the attention required to play the game may cause the group to become "too focused" or lose the ability to search for information because they are used to information being directly in front of them.

The Wonderlic only had an effect for time and did not have any main effect for group or interaction of time by group. This is not that surprising for the Wonderlic. It is a test that looks at fluid and crystallized IQ for general problem solving, math, and reasoning. The concept of IQ is that it is a constant and scores generally remain stable during a person's lifetime. Although participants performance did improve slightly from pretest to posttest, it is not surprising there were no group differences in the amount of change from pretest to posttest and the gains were likely due simply to increased familiarity with the test.

The PASAT results showed participants improved performance on each test over time. There was a significant effect of time x difficulty. That interaction showed that scores improved from pretest to posttest for all difficulty levels, but at different rates. The lack of a control group raises the question if this is just a practice effect or if it is a treatment effect. In any event, because there was no group interaction, this means that measures of attention might not be as sensitive to the combined effects of cognitive and physical training.

Overall this study provides initial support for the hypothesis that the both group would experience cognitive gains that were not seen in the game only group. In particular, slightly larger improvements were observed when it came to the Stroop interference test which is a frontal lobe task expected to be sensitive to the effects of a combined program. Exercise also improved scores on the interference test and both of the groups that received exercise improved on the set-switch task (another measure of EF). Thus, the results overall indicate that a short-term exercise intervention results in improve EF performance for young, active, college-educated adults and suggest that combining cognitive and physical training may result in even greater effects for certain measures of EF. In contrast, the game condition produced negative results in some of the measures. It could be that the game was not a good representation of learning software that can produce results for these measures. It could mean that there is something happening during the game software training that produces little to no change in score on some measures. Therefore, since the game condition by itself may be detrimental, there must be something about adding cognitive activity to exercise that could produce improvements in performance.

Limitations

This study was designed to look at changes in cognitive performance over time when exercise is combined with learning. One major limitation to this study was that the intervention conditions only lasted 6 days. Other studies that combine exercise and cognitive engagement with humans last between 14 days (Small et al., 2006) to 10 weeks (Masley, Weaver, Peri, & Phillips, 2008) to even a year (Van Uffelen, Chinapaw, Mechelen & Hopman-Rock, 2008). This study was therefore a very short intervention. This could preclude some results and produce less significant data. Therefore, future intervention studies should investigate combining exercise and cognitive training for longer. Still, since this study was only 6 days long and there were significant results, it suggests that even very short chronic physical activity interventions can increase cognitive performance.

Another limitation comes from the limited environmental control. While research was being conducted in the lab, there were many factors that could not be controlled. For example, construction was occurring below the testing room to install new facilities for athletes at the university. Loud sounds and noise happened at random intervals and durations. Construction happened from 7 a.m. to 6 p.m. 6 days a week. At times, test recordings had to be stopped so that the construction noise did not interfere with task comprehension or completion. Unwanted loud sounds can create an environment that is not conducive to learning, and this might have minimized the ability to observe learning effects in this study. Noise, is psychological phenomenon that can create feelings of stress, frustration and (Ljungberg & Neely, 2007). Not to mention, noise can cause arousal. Arousal can lead to decrements in learning and memory performance (Smith, 1991).

Additionally, although participants were randomly assigned to treatments, the pretest scores for the groups were not equivalent. This is problematic when interpreting the improvements from pretest to posttest as a function of group because it is not clear whether differential gains are due to the initial performance (i.e., a floor effect) or to the treatment itself. In the future, researchers should consider either using a familiarization period to insure that performance is stable before random assignment or matching for pretest performance before randomly assigning to groups.

The last limitation relates to the sample that was used in this study. Previous studies examining the effects of combined cognitive and physical training have all used older adults. For example, Van Uffelen, Chinapaw, Mechelen and Hopman-Rock (2008) used older adults (70 – 80 years old). They all also had MCI and were not very active. In contrast, the participants in this study were very active, young and currently attending college. Other research would argue that the younger group would not get benefits as observed in the older adults. Salthouse et al. (2003) conjecture that as we age we lose tissues and therefore some cognitive functionality. One possible way to avoid this phenomenon would be to consider the cognitive reserve hypothesis. This hypothesis says that as we age we lose tissue and functionality, in order to stave off that loss we need to build up our cognitive reserves. To build up our cognitive reserves we need to make sure that we keep challenging our brain much like we do keep our muscles active. Thus, researchers may assume that this study could have failed to show significance because the population was already college educated and have high cognitive reserves. However, the results of this study did show significance. Therefore researchers could investigate if this type of simultaneous intervention could actually be larger in populations expected to benefit more.

The participants for this study were also very fit. It is not yet understood what the results of this type of intervention would be if the sample population were sedentary. It is possible that fitness is a possible moderator for this relationship. This means that there may not be as large of an effect because the population was highly fit. Still, significant effects were shown with this group. Other studies should investigate the size of an effect with a sedentary population or low active population.

Future Directions

Future researchers should explore the psychophysiological reactions to exercise. Past research supports the importance of a several physiological mechanisms that might explain the cognitive benefits. These include neurotropic factors (Berchtold et al., 2001) that are building up or strengthening neuronal tissue and therefore creating a better cognitive environment or resources for the brain. Another mechanism may be different endogenous sex steroids like estradiol and testosterone can also be linked to cognitive performance (Wolf & Kirschbaum, 2001). Stress and the hypothalamic pituitary axis (HPA) axis could be another possible mechanism (Spalding Lyon, Steel, & Hatfield, 2004). Using a longer-term study on exercise and learning and assessing potential underlying mechanisms would contribute to understanding how these cognitive benefits accrue.

Of the evidence we have on exercise and cognition, most of the studies look at adding a cognitive training program before or after exercise. This study was designed to combine the two to increase cognitive scores to a greater extent than either exercise or cognitive training alone. The results of this study showed that exercise and cognition together produced significant changes in performance over time for the Stroop test and the Stroop interference test. One thing research has not investigated is the optimal intensity for a simultaneous exercise and cognitive training intervention. Intensity was chosen for this study based upon past research, but the ideal intensity for exercise alone might not be the same as the ideal for exercise with simultaneous cognitive training. Future studies should investigate that relationship to identify the intensity level that would produce the greatest retention and performance increases.

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APPENDIX A. TABLES

Table 2.

Wonderlic Scores by Group

	Pretest		Posttest	
Group	*M*	*SD*	*M*	*SD*
Bike	21.88	4.91	24.88	4.76
Game	23.63	5.32	25.63	6.02
Both	20.00	2.20	22.13	2.36

Table 3.

Group Means and Standard Deviations on Stroop Subtests

	Word		Color		Color-Word	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Bike						
Pre	21.66	4.61	25.46	6.25	35.73	7.12
Post	19.69	1.84	23.83	7.68	31.67	6.49
Game						
Pre	20.79	2.65	23.20	3.24	33.83	7.49
Post	20.29	4.53	21.38	3.37	33.83	12.23
Both						
Pre	21.33	3.69	24.04	3.01	38.59	6.66
Post	20.18	3.4	22.18	4.75	32.84	6.72

Table 4.

Stroop Interference Scores by Group

	Pretest		Posttest	
Group	*M*	*SD*	*M*	*SD*
Bike	12.17	4.11	9.91	2.94
Game	11.83	5.64	12.99	10.73
Both	15.91	4.34	11.66	3.23

Table 5.

TMT Scores by Group

	TMT A				TMT B			
	Pre		Post		Pre		Post	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Bike	27.3	5.22	21.46	5.8	54.46	8.3	44.26	6.36
Game	34.52	11.83	25.31	7.77	63.15	18.74	58.05	18.11
Both	25.06	7.5	23.66	8.03	54.06	12.25	45.92	14.09

Table 6.

Set-Switch Scores by Group

	Pretest		Posttest	
Group	*M*	*SD*	*M*	*SD*
Bike	27.16	6.98	22.80	8.13
Game	28.63	13.61	32.74	12.58
Both	29.00	10.17	22.26	15.61

Table 7.

PASAT Means and Standard Deviation by Group

	Traditional Scoring							
	2.4”		2.0”		1.6”		1.2”	
Group	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
Bike								
Pre	45.9	(8.6)	44.0	(5.8)	38.1	(8.3)	24.6	(7.7)
Post	54.0	(4.3)	48.6	(7.1)	43.0	(8.6)	27.7	(7.3)
Game								
Pre	39.6	(12.6)	33.0	(11.2)	26.25	(14.0)	17.9	(10.0)
Post	43.5	(12.0)	37.4	(11.3)	31.0	(17.2)	19.0	(11.7)
Both								
Pre	35.1	(9.6)	32.5	(8.1)	25.5	(6.3)	18 .0	(10.0)
Post	44.8	(6.8)	37.0	(9.3)	32.9	(9.0)	21.4	(7.8)
	Lezak Scoring							
	2.4”		2.0”		1.6”		1.2”	
Bike								
Pre	34.1	(13.3)	27.6	(9.6)	20.7	(11.4)	7.1	(7.2)
Post	45.3	(9.5)	35.0	(12.4)	27.0	(12.1)	10.4	(8.0)
Game								
Pre	32.6	(14.7)	19.3	(9.7)	17.1	(12.4)	6.8	(5.6)
Post	37.4	(17.5)	29.0	(17.5)	24.0	(17.5)	9.8	(8.5)
Both								
Pre	20.1	(13.5)	18.0	(10.6)	12.1	(7.5)	5.3	(6.8)
Post	32.8	(10.5)	23.8	(13.1)	18.9	(12.1)	9.1	(7.7)

Table 8.

TMT Means by Subtest

	Pretest		Posttest	
Test	*M*	*SD*	*M*	*SD*
A	28.96	(9.22)	23.48	(7.13)
B	57.23	(13.85)	49.41	(14.56)

APPENDIX B. FIGURES

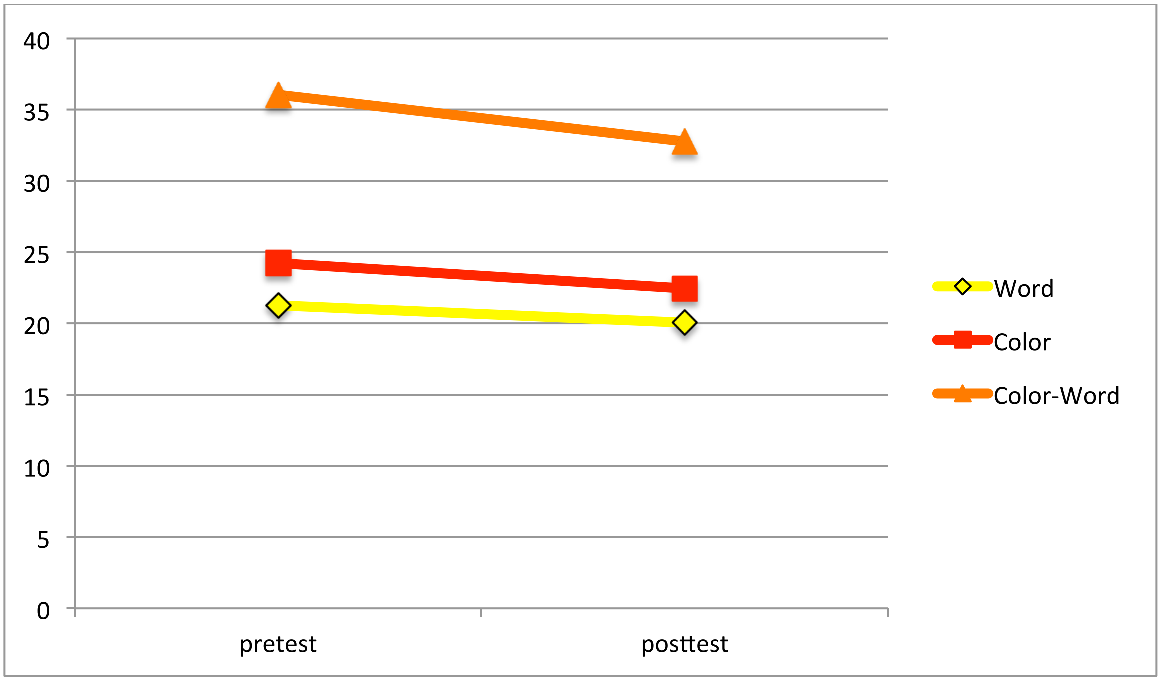

Figure 1. Interaction of time x test for Stroop

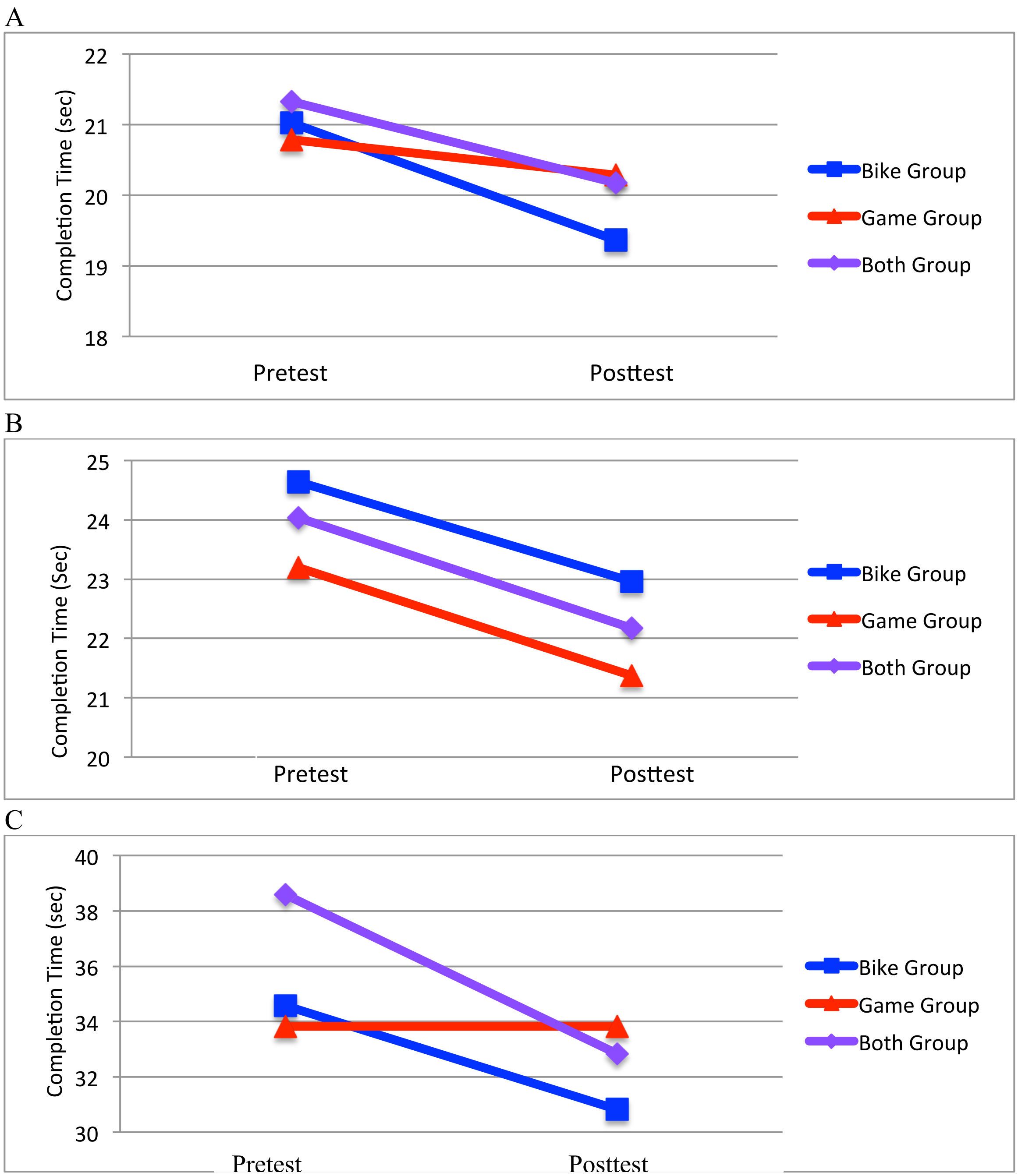

Figure 2. *Changes in group score for Stroop subtest for word (A), color (B), and color-word (C).*

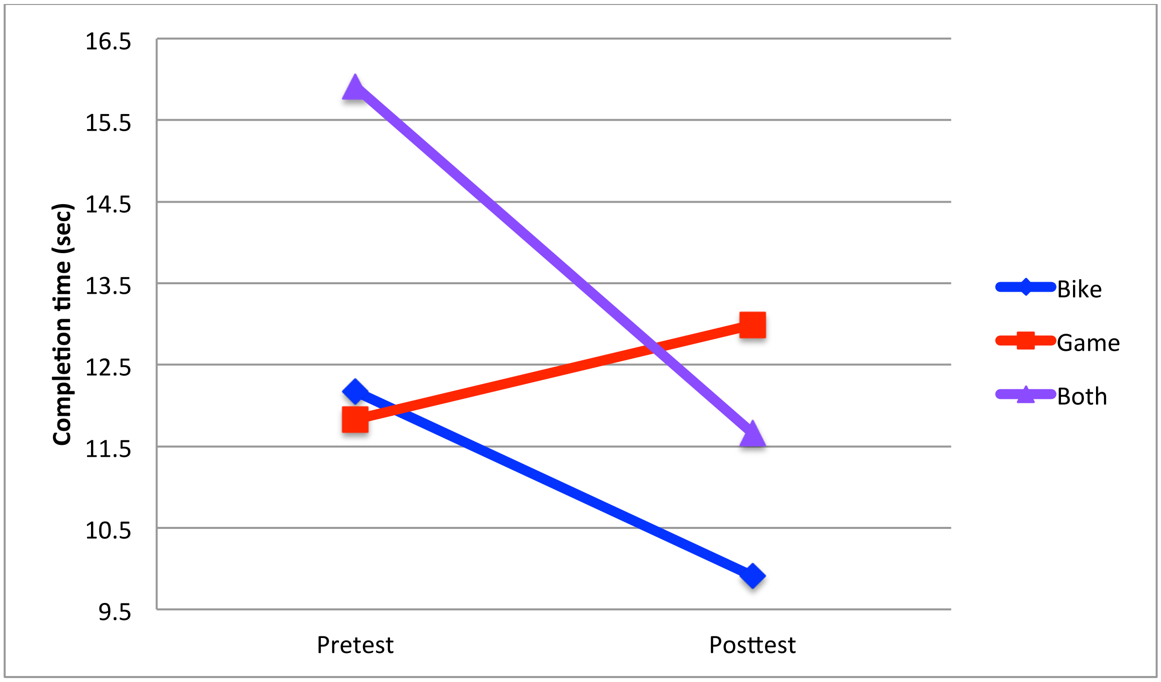

Figure 3. *Interaction of group by time for Stroop Interference test.*

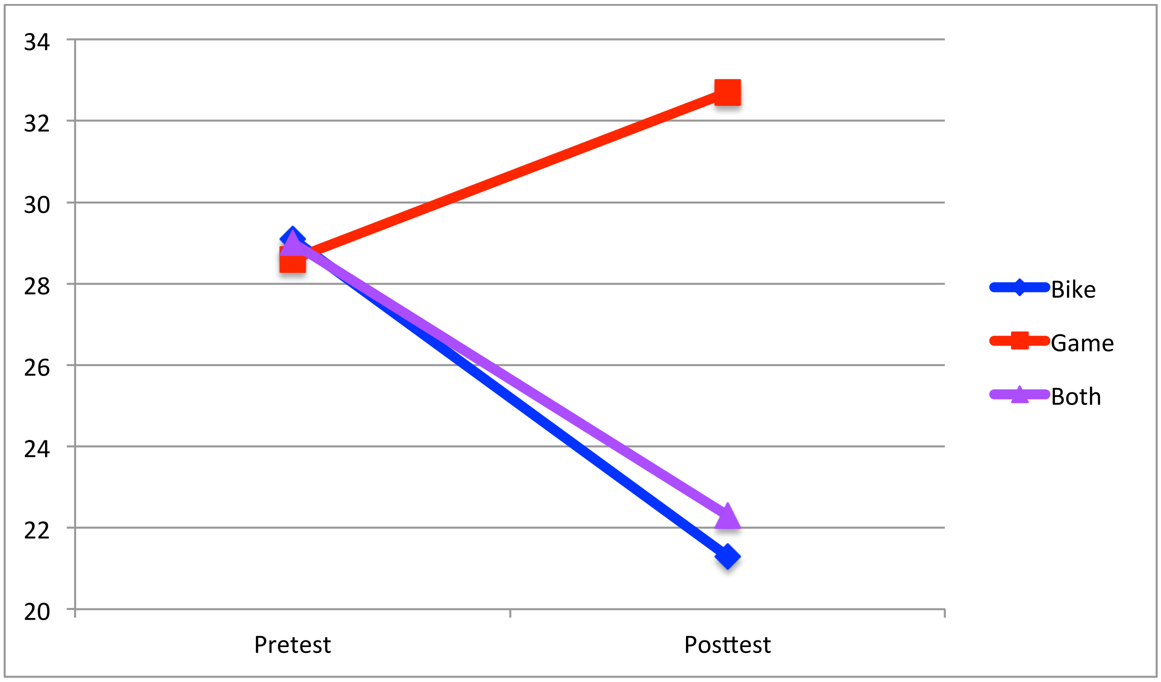

Figure 4. *TMT Set-Switch Interaction Time x Group (p = .068).*

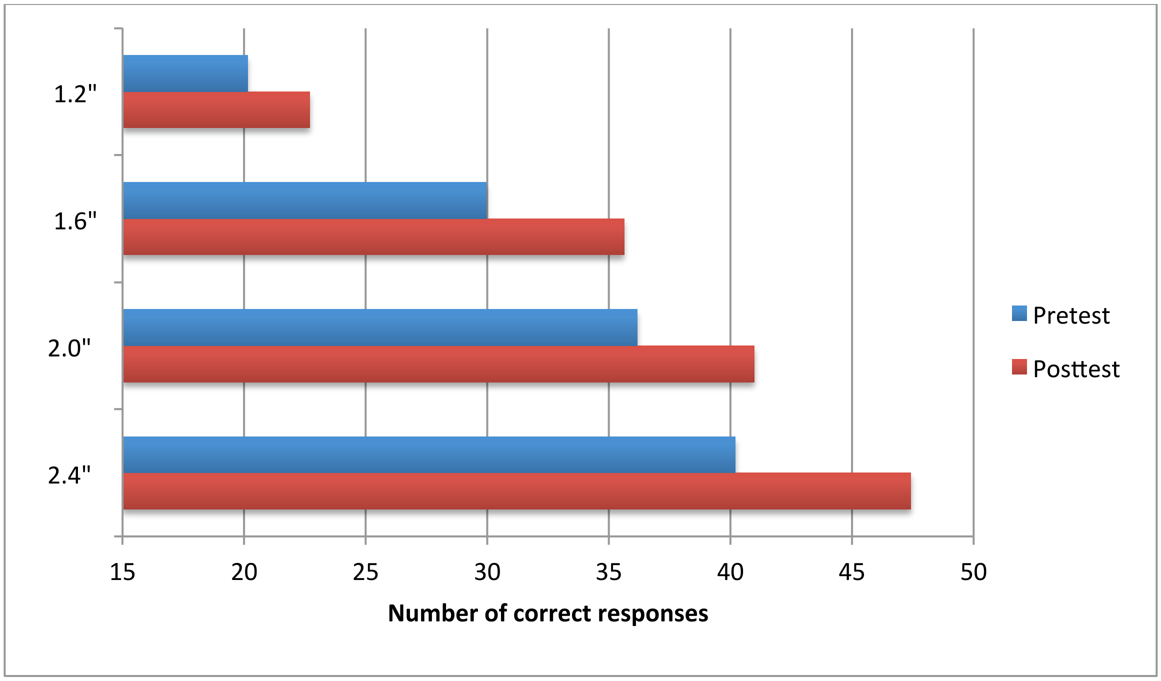

Figure 5. *PASAT traditional scoring interaction of time x difficulty.*

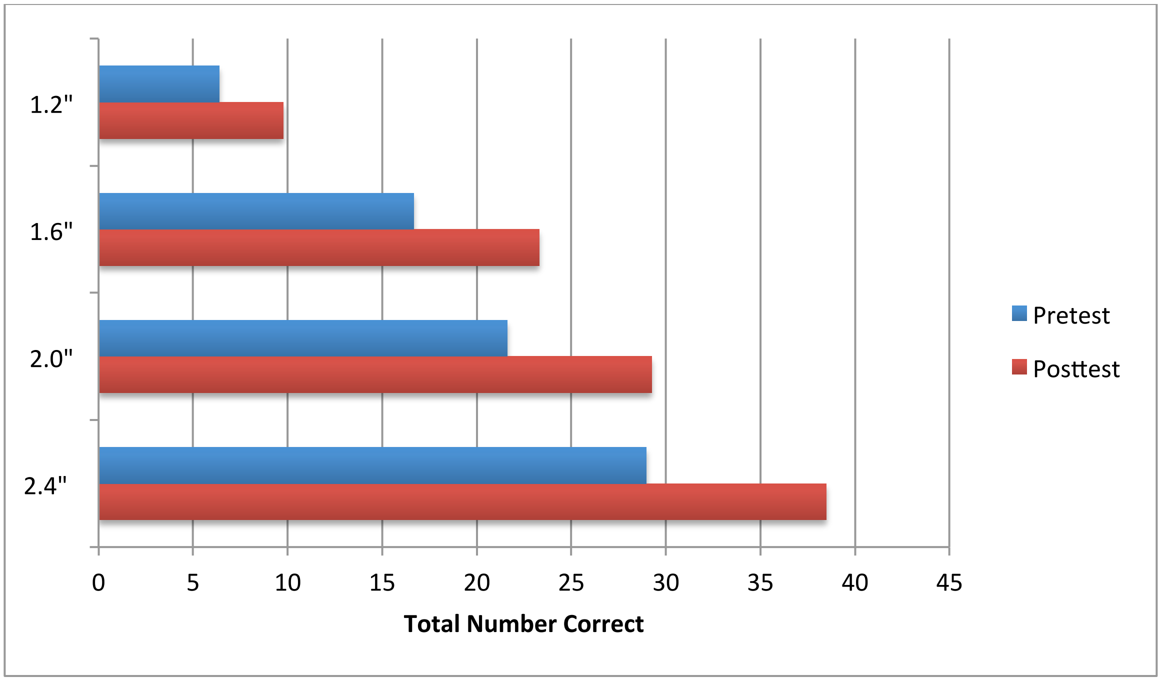

Figure 6. PASAT LEZAK scoring time x difficulty interaction (p = .077).

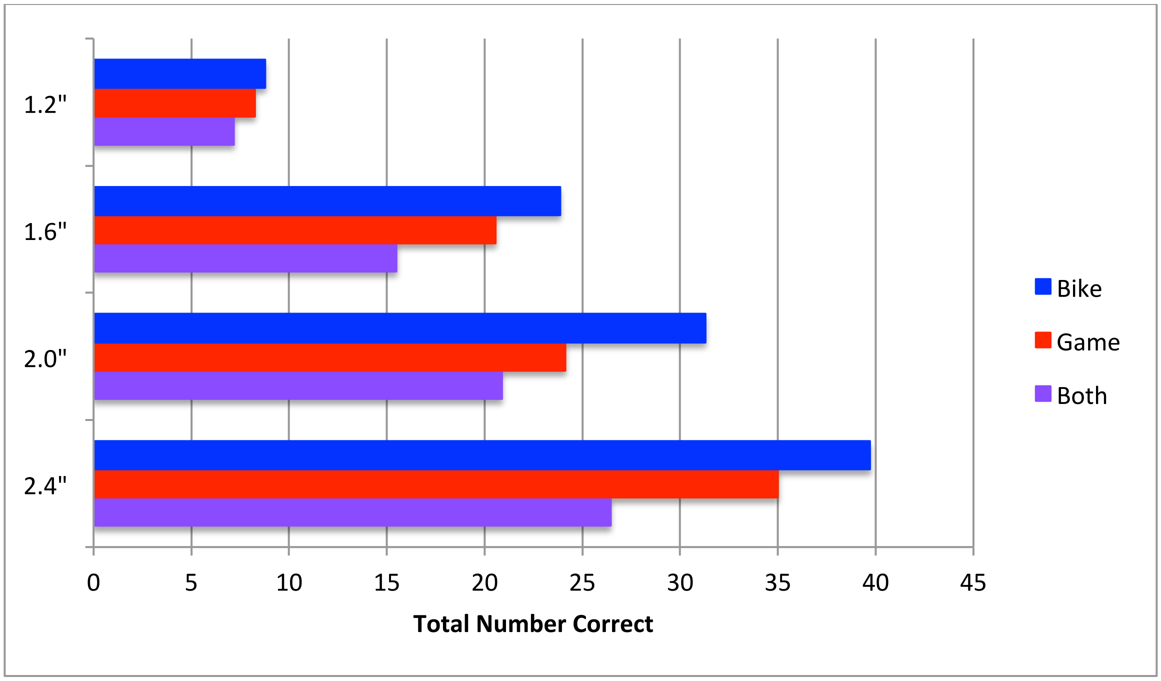

Figure 7. *PASAT LEZAK scoring interaction of difficulty x group (p = .051).*