Cognitive Effects of Combined Physical and Mental Exercise: Interactive vs. Synchronous

By

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ABSTRACT

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Cybercycling For Cognitive Health:

Combined Physical and Mental Exercise Immediately Enhances Executive Function

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Many high quality randomized clinical trials have now clarified the strong relationship between exercise and cognition (Colcombe & Kramer, 2003). A growing area of exercise research has been focused on the effects of "exergaming" on cognitive function. Exergaming provides an individual with the ability to physically interact with a virtual environment (O'Leary et al., 2011). Recent research has shown an added cognitive benefit of interactive mental and physical exercise, when using a virtual reality-enhanced stationary bike. It is unclear whether interactivity is required, or if added cognitive benefit is "simply" from doing two things at the same time and reaping extra benefit. This study randomly assigned participants to one of three conditions: 1) interactive mental and physical exercise (cybercycling), 2) synchronized mental and physical exercise (watching an educational TV program while pedaling), or 3) mental exercise only. Thirty participants engaged in an acute exercise bout and completed neuropsychological tests of executive function, pre and post exercise. Participants were characterized as fit or unfit by the exercise history questionnaire (McAuley et al., 2011). There was a significant effect of combined physical and mental exercise with fit participants on executive function as measured by the Color Trails Difference scores, $F(1,21) = 4.98$, $p < 0.05$, such that participants who engaged in either the

interactive or synchronized condition had a larger improvement in executive function (M = -2.90) compared to the mental exercise group (M = 9.61). The negative mean indicates that the participants performed faster on the post-test. These findings suggest that interactive or synchronized exercise, is more beneficial than mental exercise alone. However, more research is needed to clarify if there really is a difference between interactive and synchronized exercise. A larger sample size may reveal if there is a difference, which was not able to be detected here.

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INTRODUCTION

Interest in the relationship between the mind and body can be traced back to ancient civilizations. One philosopher in particular, René Descartes, famously advocated for the idea that the mind and body are separate entities (Descartes, Cottingham, Stoothoff, & Murdoch, 1984). However, since the seventeenth century there has been a multitude of evidenced based research that has demonstrated that there is a link between the mind and the body. Formal investigations into the relations between physical activity and cognition began in the 1930s, and research is continuing to expand into the twenty-first century (Hillman, Erickson, & Kramer, 2008). Since then, it has been shown that physical activity is associated with the reduction of a number of illnesses, such as cardiovascular disease, various cancers, and obesity among others (Hillman et al., 2008). Physical exercise has also been identified as a possible mechanism to prevent cognitive decline in older adults (Tomporowski, 2003). One disease in particular that is a rising concern is dementia.

Dementia is a condition that refers to the deterioration in cognitive functioning, which not only affects the lives of individuals, but everyone around them. The incidence of dementia, such as that due to Alzheimer's disease, affects more than twenty-four million people worldwide (Bekris, Yu, Bird, & Tsuang, 2010). The number of cases has risen exponentially with no indication of leveling off (Plassman et al., 2007), which has made research in this field increasingly important. Currently, there is no cure for dementia; however, there is a growing area of research interested in identifying intervention therapies that might delay the onset of this neurodegenerative disorder. Most of the current research has focused on older adults, however data has suggested that the benefits of physical activity span across one's lifetime (Clarkson-Smith & Hartley, 1989; Sherwood & Selder, 1979; Spirduso, 1975). Thus, if individuals start taking preventative measures early on in life, they may be able to accrue a larger cognitive reserve, which may delay cognitive decline. The current study hopes to contribute to this growing area of research on interventions, by first focusing on possible effects of certain types of physical activity interventions in younger adults, who are currently underrepresented in the related literature (Hillman et al., 2008).

The Effects of Exercise

Exercise as a natural form of cognitive enhancement is not a new concept in the research field of neuropsychology or medicine; many high quality randomized clinical trials have now clarified the strong relationship between exercise and cognition (Colcombe & Kramer, 2003). Colcombe and Kramer (2003) conducted a meta-analysis on eighteen different intervention studies published between 1996 and 2001 to further understand this relationship. In this study, the researchers compared four different hypotheses that were proposed in previous research to identify what area of the brain exercise targets. The first hypothesis was *the speed hypothesis*, which stated that physical activity was specific to simple reaction tasks. The second hypothesis was *the visuospatial hypothesis*, which stated exercise was specific to visuospatial tasks. The third and fourth hypotheses were *the controlled-processing hypothesis* and *the executive-control hypothesis*, respectively. The participant population was older adults, fifty-five to eighty-eight years of age. The researchers excluded studies that were cross-sectional, not randomized, unsupervised, or programs that did not include an aerobic fitness component. Results showed that physical activity increased performance in all four cognitive domains (0.5 *SD* on average), regardless of the type of cognitive task, training method, or participant characteristics (Colcombe & Kramer, 2003). However, the largest exercise-induced effect was for executive-control processing. This study concludes that physical activity has robust but selective benefits for cognition, and the magnitude of the effects is mediated by the length of the exercise intervention, the type of intervention, and the duration of the session.

One earlier study conducted by Clarkson-Smith and Hartley (1989) found similar cognitive benefits of physical exercise in older adults, however focused specifically in the areas of working memory. The researchers found similar results as Colcombe & Kramer (2003), but also categorized participants based on high or low physical activity intensity. This allowed the researchers to examine differences in physical fitness as a possible explanation to why people obtain varying cognitive benefits from exercise. The high intensity exercise group had to have expended a minimum of 3100 kilocalories per week and participated in a minimum of an hour and fifteen minutes of strenuous exercise per week. The low intensity exercise group had to have expended no more than 1900 kilocalories and participated in no more than ten minutes of strenuous exercise per week. These two groups can be thought of as fit and unfit respectively. In the first hour and a half session, the two groups completed an exercise interview, a vocabulary test, three tests of working memory, and three tests of reaction time. In the second hour and a half session, the participants completed three written tests of reasoning and two subjective well-being questionnaires. Researchers found that the high intensity exercise group performed significantly better in all three tests of reasoning, in two of the tests of working memory, and in all three measures of reaction time. The researchers did a multitude of tests to confirm that the significant differences between the groups were not due to medical conditions, medications, or participants' overall feelings on health. This trend of physical activity leading to better cognitive functioning is consistent with previous literature that has documented the effects of physical activity in fit individuals across age groups (Sherwood & Shelder, 1979).

Sherwood and Shelder (1979) compared the reaction time of participants that spanned the ages of twenty-three to fifty-nine. This study helped to clarify the role that fitness plays to mediate the effects of exercise on cognitive function, which was not looked at in Colcombe & Kramer (2003). This study separated participants by age, which was not done by Clarkson-Smith & Hartley (1989). This separation is important to see if certain ages benefit more cognitively than others from exercise interventions. In this study, half of the subjects were runners involved in rigorous training programs and the other half were sedentary adults. The participants were separated according to their physical activity, as either trained or sedentary. The groups were further divided by age. In the trained group, the average miles per week for each age group was: 35.7 miles per week for ages twenty to twenty-nine, 44.4 miles per week for ages thirty to thirty-nine, 37.1 miles per week for ages forty to forty-nine, and 34.4 miles for ages fifty to fifty-nine. The subjects all completed eighty simple and one hundred choice reaction time trials. Results indicated that in the sedentary group there was a gradual decline in reaction performance as age increased. In contrast, in the physically active group reaction times remained constant with age. This study suggests that a high state of cardiorespiratory training may prevent cognitive decline with age (Sherwood & Shelder, 1979).

Spirduso (1975) conducted a similar study that compared the differences among groups of old and young adults, however it distinguished participants who were fit throughout their lifetime. This differs from the more current studies that may have had participants who were only physically fit for a small period of time in their lives and consequently their brain may not have had enough time to obtain the cognitive benefits of regular physical activity. This distinction allowed the researchers to examine more concretely how fitness mediates the cognitive benefits from exercise interventions. The role of fitness is important to track in order for researchers to determine what age participants should start to engage in physical exercise to maximize their cognitive reserve. In this study, participants were all males who were either: active throughout their lifetime, inactive throughout their lifetime, active young adults, or inactive young adults. To be categorized as active, participants had to have participated in squash, racquetball, or handball for a minimum of three days per week. Whereas, participants who were deemed to be active throughout their lifetime had to have participated in these activities for at least thirty-years, the active young adults had to have participated in one of these three sports for a minimum of three years. The participants completed a series of reaction time tests. Results suggested that there was a significant main effect for activity-level and age for all variables, where when the active groups was averaged over age, they were significantly faster than the inactive groups. In two out of the three measures of reaction time, the two active groups were faster than both the inactive groups. Interestingly, there was only an eight percent difference in the speed of the young adult groups; however, in the older adults the inactive group was twenty-three percent slower than the active group. This study suggests that a lifetime of physical activity may play a more significant role in determining reaction speed than age alone (Spirduso, 1975). In addition to physical activity, there has been evidence that mental activity can also produce cognitive benefits.

Mental Exercise

Mental exercise can be thought of as any exercise that stimulates the mind, such as a videogame, an educational television show, a computer course, or learning a new language. Most of the current research has focused on the effects of videogame and computer play on cognitive function. Evers, Klusmann, Schwarzer, and Heuser (2011) conducted a study that compared the effects of physical exercise and mental exercise on older adults. Participants were all inactive adults between the ages of seventy and ninety-three. The subjects were randomly assigned to one of three conditions; the physical exercise intervention, the mental exercise intervention, or the sedentary control group. The study was conducted over a period of six-months, where participants were evaluated with a neuropsychological battery pre and post exercise intervention. The neuropsychological battery consisted of tests of episodic and working memory, executive attention, and semantic verbal fluency. Results found that in both the physical and mental exercise groups, participants performed significantly better over time compared to the control group. The study found that participants in the two intervention groups performed better on the post test, whereas the control group decreased in performance on their post-test. Interestingly, the researchers found that there was a significantly higher adherence rate in the computer intervention (85%) compared to the physical exercise intervention (69%). This suggests that there is something about mental exercise that not only provides cognitive benefits, but also keeps normally sedentary participants engaged.

Basak, Boot, Voss, and Kramer (2008) completed a similar study that examined the benefits of videogame play on executive function and visuospatial skills. In this study, forty participants were randomly assigned to either the videogame training condition or the control group. The participant population was older adults between the ages of sixty and eighty years of age. The videogame used in this study was of a high level of difficulty and kept participants engaged throughout the entire session. The study spanned seven to eight weeks, depending on the subjects' assigned testing sessions. The subjects in the experimental condition completed fifteen hour and a half sessions of videogame play, resulting in a total of twenty-three and a half hours of videogame play. The subjects also completed three neuropsychological evaluations, one pre-intervention, half way through the intervention, and post-intervention. The neuropsychological battery was comprised of six tests of executive function and four tests of visuospatial attention. The videogame group improved significantly more than the control group in all measures of executive function and one measure of visuospatial attention. This study questioned if the same effects would be obtained with a less challenging videogame that did not involve the same amount of mental resources as the game used in this study. This study suggests that mental exercise, such as videogame play, can result in cognitive benefits in areas of executive function.

In addition to long term intervention studies, Orosy-Fildes and Allan (1989) examined the effects of single bout videogame play in young adults. The college-aged participants were randomly assigned to either the videogame experimental condition or the control condition. Participants in the experimental condition played fifteen minutes of a Centipede videogame on an Atari 2600 gaming system. Participants in the control group did not play a videogame and sat silently in a room for fifteen minutes. Participants completed twenty reaction time trials before the exercise intervention and immediately after the intervention. Results found that single bouts of videogame play aided in significantly reducing participants' reaction time by an average of fifty milliseconds, thus improving their cognitive function. Furthermore, participants in the experimental condition had consistently lower mean scores on the post-test, whereas participants in the control condition had an increase in reaction time in almost half of the trials. This study further supports the idea that mental exercise, like physical exercise, is beneficial for cognitive functioning.

In contrast to the previous research study, Lichtman and Poser (1983) found that acute bouts of physical exercise and mental exercise do not produce the same cognitive benefits. Participants in this study were between the ages of seventeen and fifty-four. Participants were randomly assigned to either enroll in an exercise class or a hobby class at a local community college. The exercise class participated in jogging or other various physical activities for several forty-five minute sessions. The hobby group participated in classes that ranged from painting and photography to typing and nutrition. Participants completed a neuropsychological battery before and after each session. There was a significant main effect from pre-test to post-test for the physical exercise group on all Stroop measures, indicating that there was a significant positive effect on executive function, which was not apparent in the hobby group. This suggests that physical exercise may be more beneficial than mental exercise; however, this could have resulted from the mental tasks not being challenging enough. These contrasting results suggest that there is still much research that needs to be conducted to understand the effects of mental exercise on cognitive functioning.

Through this research, it has been shown that exercise has beneficial effects on a variety of areas of the cognition; however, the largest effect has been in executive function. Despite the conclusions of research, most adults still do not engage in regular physical activity. The need for exercise was highlighted in the CDC Healthy People 2010 Database, which indicated that only fourteen percent of adults between the ages of sixty-five and seventy-four and seven percent of people aged seventy-five and older reported regular physical activity (Center for Disease Control and Prevention, 2010). The need for physical activity is not limited to the adult population; it has been shown that young adults who engage in regular physical activity have better cognitive function throughout adulthood (Clarkson-Smith & Hartley, 1989; Sherwood & Selder, 1979; Spirduso, 1975). Therefore, there is a need for a type of exercise that will motivate all age groups to pursue a healthier lifestyle. One type of exercise that has been correlated with high enjoyment and participation is a combination of mental and physical exercise, which is known as exergaming.

The Effects of Exergaming

A growing area of exercise research has been focused on the effects of "exergaming" on cognitive function. Exergaming incorporates both physical and mental activity. Exergaming provides individuals with the ability to physically interact with a virtual environment; their specific movements are captured and depicted on a screen via a virtual character (O'Leary, Pontifex, Scudder, Brown, & Hillman, 2011). Exergaming has also been shown to have similar cognitive benefits as traditional exercise (Anderson-

Hanley et al, 2012). However, they also have the intrinsic attractiveness of videogames, which makes them a great tool to increase participation in regular physical exercise (Maillot, Perry, & Hartley, 2011).

A recent study conducted by Anderson-Hanley and colleagues (2012) examined the effects of cybercycling and traditional exercise through a three-month exercise intervention. The participant population used in this study was older adults. Participants were randomly assigned to either a stationary bicycle condition or a cybercycle condition. One key difference between the stationary bicycle and the cybercycle is the inclusion of the cognitive exercise component, which makes it function as an exergame. Participants randomly assigned to the cybercycle engaged in virtual 3D scenic tours and competed virtually with avatar riders. This videogame-like atmosphere, requiring participants to race against other virtual competitors and by following the virtual course, shows the mental effort component intertwined with the physical activity. Participants were assessed on their cognitive function through a standard neuropsychological battery at enrollment (baseline), one month into the study (pre-intervention), and three months later (post-intervention). The primary cognitive domain of interest was executive function, which is consistent with previous research that found executive function to be the main target of exercise (Colcombe & Kramer, 2003). Results indicated that there was a medium average effect size ($d = 0.50$) for executive function in the cybercycle group, which was larger than the average effect for traditional exercise. Furthermore, exercise adherence was about eighty percent, which is an extremely high percentage; this was true across both conditions and there were no significant differences in exercise effort or frequency. So, for similar physical effort, this suggests that exergaming is a better alternative to traditional exercise for older adults. Cybercyclists also experienced a greater increase in BDNF than traditional exercisers, which also is comparable to previous literature that documented an increase in BDNF levels following an exercise intervention (Gold et al., 2003; Hillman et al., 2008). This study furthermore suggested that exergaming has greater potential for preventing cognitive decline than traditional exercise; that is, cybercyclists experienced a lower rate of conversion to MCI than among the traditional cyclists (Anderson-Hanley et al., 2012).

In addition to comparing cognitive benefits, researchers questioned if exergaming elicited comparable physical intensity to traditional exercise. A study conducted by Haddock et al. (2012) investigated if the intensity of an exercise was minimized when an interactive virtual reality component was introduced. In this study participants were instructed to exercise for thirty minutes five-times per week at a self-selected intensity. All participants were between the ages of eighteen to thirty-five. The exergames that were used were “Your Shape”, “Just Dance” and “The Biggest Loser: Ultimate Workout.” These three games involve a virtual character that is depicted on a screen in front of the participant; the virtual character will complete various physical exercise routines and the participants are instructed to mimic the virtual character’s movements on the screen. The participants have a monitor that determines the accuracy of the participant’s movements. This is an important study, because it shows the normal behavior a person will exhibit during an exercise session by allowing them to self-select their intensity. It was found that participants exercised at a heart rate intensity of 44.6+/-14.1% of their heart rate reserve; which is considered to be moderate-intensity exercise (Haddock et al., 2012). If participants incorporated this exercise regime into their daily lives, they would meet the American College of Medicine's recommendation for weekly energy expenditure (Haddock et al., 2012). This suggests that exergaming could be an alternative to traditional exercise, due to participants independently choosing to exercise at an intensity that will allow them to gain cognitive benefits.

Kraft, Russell, Bowman, Selsor III, and Foster (2011) showed similar results as Haddock et al. (2012) with a population of college students. This study compared heart rate and perceived exertion during self-selected intensities for exergaming and traditional exercise. Participants engaged in a single thirty-minute acute bout workout. The researchers had participants exercise in an exergame condition, which included an interactive bicycle ergometer game, CatEye; an interactive video-dance game, *Dance Dance Revolution*; or a traditional exercise condition, which consisted of bicycling while watching a television show. Target heart rate was determined based on the Karvonen method, where participants exercised at an intensity equal to forty-percent of their heart rate reserve (Karvonen, Kentala, & Mustala, 1957). Results showed that heart rate and physical benefits increased significantly more during the exergame cycle than in either the video dance or traditional cycle. Furthermore, participants in the cybercycle condition spent an average of seventy-five percent of their time above their target heart rate, whereas participants in the video dance condition spent an average of thirty-seven percent of their time above their target heart rate, and the traditional exercise condition spent an average of forty-seven percent of their time above their target heart rate. This study further supports the findings that acute bouts of exergaming exceeds the physiological benefits and intensity of traditional exercise. Aside from the physiological benefits of exergaming, psychological researchers have debated the adequate level of exercise needed to optimize the use of mental resources and thus cognitive processing. Current research has suggested that an acute bout of exercise is sufficient in manipulating cognitive function (Best, 2012; Chang, Labban, Gapin, & Etnier, 2012; Mailot et al., 2011; O'Leary et al., 2011; Roig, Skriver, Lundbye-Jensen, Kiens, & Nielsen, 2012).

Roig et al. (2012) investigated how the timing of exercise could optimize the acquisition and retention of its cognitive benefits. The participant population focused on young adults between the ages of eighteen and thirty-five. Participants were randomly assigned to either exercise before completing a visuomotor accuracy-tracking task, exercise after completing the visuomotor accuracy-tracking task then exercise, or complete the visuomotor accuracy-tracking task after rest. Each intervention period lasted for twenty minutes. Motor skills were assessed during practice and retention was measured one hour, twenty-four hours, and seven days after practice. Results showed that both exercise conditions had better retention of the motor skills twenty-four hours and seven-days after practice compared to the control. Furthermore, participants who exercised after the visuomotor accuracy-tracking task had a better retention of the motor skills seven days after practice compared to all other conditions. This study shows that intense acute bout exercise sessions can improve retention of motor skills and the time of the exercise intervention matters.

Maillot et al. (2011) conducted a study that assessed the ability of exergame training to transfer into other cognitive skills. The researchers believed that the transfer of the cognitive benefits of exergaming into other cognitive domains would depend on the difficulty of the game, motivation, variability, and arousal. The study used a pre-test post-test design that compared an experimental group (24 x 1 hr of training) with a control group that received no treatment on areas of cognitive function. The Nintendo Wii gaming system was used in this study due to its accessibility, novice difficulty, and appeal to people of all ages. The researchers also assessed the physical impact of the program on a battery of functional tests. Results suggested that exergaming led to improvement in physical function, executive function, and processing speed. One limitation is that this study lacked a physical activity control group. Due to this limitation, the researchers cannot conclude if the added cognitive challenge in the exergame added any more cognitive benefits than physical exercise alone. Although this study lacked a control group, the results portrayed a trend similar to the previous work (Anderson-Hanley et al., 2012; Haddock et al., 2012; Kraft et al., 2011). This study had about a ninety-eight percent adherence and participants even asked to continue exercise after the session was completed. This is consistent with the high adherence rate seen in the study conducted by Anderson-Hanley et al. (2012).

A study conducted by O'Leary et al. (2011) expanded the cognitive benefits of acute bout exercise to include inhibitory aspects of cognitive control. The researchers predicted that single bouts of moderate aerobic exergaming would enhance cognition as measured by task performance and the P3 component on ERPs, which would replicate in part previous research (Hillman et al., 2003; Kamijo et al., 2009; Pontifex et al., 2009). Physical exercise participants were expected to exhibit P3 components with larger amplitude and shorter latency and also have shorter reaction times when compared to the sedentary conditions on the cognitive tasks. The study used college aged participants and randomly assigned them to one of four conditions: seated rest, Mariocart the videogame, treadmill walking, or the Wii Fit exergame. Participants were instructed to exercise at an intensity equal to sixty percent of their heart rate reserve based on the Karvonen method for a duration of twenty minutes (Karvonen et al., 1957). The study was conducted over a period of six days. On the first day participants completed basic questionnaires and were given ten minutes of practice on the video games. The following four days participants were instructed to exercise for twenty minutes in their respective conditions. Following exercise, participants completed a modified flanker test. ERP recordings and oxygen consumption assessments were recorded each day. Data revealed that heart rate did not differ significantly across the two exercise conditions, indicating that exergaming is equivalent to the intensity of traditional exercise. This is comparable to previous research (Anderson-Hanley et al., 2012; Haddock et al., 2012; Kraft et al., 2011). However, a reduction in reaction time and a larger P3 amplitude was only found in the treadmill-based exercise group. This implies that exergaming is not a valid alternative to traditional exercise. The contradicting results found in this study may be due to the exergame being more cognitively challenging than the games used in previous studies. The videogame used in this study had a changing nature and variable attentional control demands for successful completion of the task; which may have negated the beneficial changes that were elicited by the aerobic component of the game (O'Leary et al., 2011). This suggests that exergaming can be beneficial as long as the mental component is not more challenging than the aerobic component. The researchers only used the modified flanker task to assess cognition, and therefore more research should explore different areas of cognitive control with varying neuropsychological measures.

Best (2012) took this research on exergaming one step further and attempted to tease apart two important aspects of exercise. This study compared the separate and combined effects of acute bouts of physical activity on executive function and cognitive engagement. The research focused on young children between the ages of six and ten. The study used a within-subjects design, where participants completed four separate one-hour experimental sessions. Each session consisted of a twenty-three minute exercise intervention and two neuropsychological batteries that tested executive function with the flanker task. The four conditions that all participants completed varied in levels of cognitive engagement (CE) and physical activity (PA). The low CE and low PA condition had children watch a video on healthy living habits. The high CE and low PA condition had children play a sedentary videogame on Nintendo Wii entitled *Super Mario World*. The low CE and high PA condition had children play an exergame titled "Marathon" on *Active-Life: Outdoor Challenge for Nintendo Wii*, in which children had to jog in place to move their virtual character. The high CE and high PA condition had children play mini-exergames titled "Mini-Exergames" also on the same gaming system, in which participants had to jog in place and move around obstacles. The participants played ten two minute long mini-games each time increasing in difficulty, which overall amounted to twenty minutes of exercise. Physical activity significantly enhanced participants' reaction time; however, cognitive engagement had no effect. This study did not find that combined physical activity and cognitive engagement had an increased benefit over physical activity alone. One limitation to this study was that there were different mental gaming systems in each condition, which makes the results from the cognitive engagement aspect of each condition difficult to compare. There has been a multitude of research that has explored the effects of physical, mental, and combined exercise on cognitive function; however, it is still unclear exactly how exercise leads to improved brain function. This research aims to address some of the limitations of prior research and further clarify the relationship between physical and mental exercise.

Neuroscience Portion

Various studies have suggested that there are differences in the cognition of active and sedentary adults (Clarkson-Smith & Hartley, 1989; Sherwood & Selder, 1979; Spirduso, 1975), however the previous studies could not explain how their brains differ. Kamijo, Takeda, and Hillman (2011) investigated the relation between physical activity and functional connectivity between brain regions in active and sedentary young adults. The researchers used a physical activity questionnaire to distinguish between physically active and sedentary adults, which was based on the questionnaire used in the study conducted by McAuley et al. (2011). The researchers used electroencephalograms (EEG) to record participants' brain waves during a spatial priming task. Results showed that physically active individuals had greater functional connectivity between brain regions than the sedentary individuals. This study suggests that there are functional differences in the brain that could explain why fit and unfit participants display varying scores on cognitive function tests.

Colcombe et al. (2006) further explored the differences in brain structure between active and sedentary adults. Colcombe et al. (2006) suggests that regular physical activity is a significant predictor of age-related tissue lost. Through his research he has demonstrated that older adults with greater levels of aerobic fitness had significantly less grey and white matter loss in the frontal, temporal, and parietal cortices in the brain; these effects were not seen in participants who solely engaged in anaerobic exercise. This study implies that exercise can result in increased brain volume, in both the gray and white matter regions in older adults (Colcombe et al., 2006). This further suggests that there are distinct structural differences between fit and unfit adults, which is another explanation as to why there are differences in cognitive tests (Clarkson-Smith & Hartley, 1989; Sherwood & Shelder, 1979; Spirduso, 1975).

Theory I: Interactive and Synchronized Exercise Will Not Differ In Cognitive Benefits.

There are various mechanisms that attempt to explain the changes that occur in the brain from mental and physical exercise. One theory suggests that physical exercise acts to "enervate" the body and mind, preparing it for enhanced learning and cognitive function by cell proliferation and cell survival (Moore, 2012; Van Praag, 2008). Thus it would not matter if the mental activity was interactive or just simultaneous with the physical. Exercise has been suspected to improve cognitive function due to the enriched environment that it creates in the brain. Enriched environments have a positive effect on neuronal systems that are involved in learning and memory (Hillman et al., 2008). Best (2012) argues that physical activity leads to increases in physiological arousal, which in turn allows for greater allocation of attentional resources to exert over cognitive control allowing for increases in cognitive function. Furthermore, the neurotransmitters that are released during exercise, such as dopamine, norepinephrine, and serotonin, enhance certain aspects of executive function (Robbins, 2000). In animal research, physical activity creates an environment that counteracts cognitive decline, where it prevents the reduction in cell genesis completely over a six-month intervention (Van Praag, 2008). Research has suggested that it is only the physical activity (not mental exercise) that can create this enriched environment, because physical activity stimulates the metabolism, blood circulation, digestion, and the glands of internal secretions, which in turn stimulates the neuronal signaling process (Spirduso, 1975). This theory suggests that it is the physical activity alone that creates an enriched environment that leads to increased cognitive benefits, regardless of how the mental exercise is connected to the physical.

Theory II: Interactive Exercise Will Create an Additional Cognitive Benefit

Another theory states that the neuronal signaling process is more strongly enhanced when the brain is doing two exercises intertwined, due to the fact that there is neuogenesis occurring in overlapping brain regions (Van Praag, 2008). Brown et al. (2003), states that there are two components, learning and spontaneous physical activity, that independently and specifically enhance hippocampal neurogenesis. Therefore, it is not that the physical activity creates an enriched environment that leads to changes in brain and cognitive functioning, but it is that physical activity and learning can independently enhance neurogenesis and together have a combined effect. Van Praag, Kempermann, and Gage (1999) suggest that neurogenesis could be regulated by physical activity and environmental enrichment. Through this research the experimenters show that exposure to an enriched environment produces structural and functional changes, however they also show that there are significant increases in hippocampal neurogenesis.

Prior research has focused on the effects of physical exercise on cognitive aging where it has been shown to reduce the risk for dementia and cognitive impairments after two years of moderate to high physical activity intervention (Etgen et al., 2010). There are various neurological changes in late adulthood, one being the shrinking of the hippocampus, which can lead to impaired memory and increased risk for dementia (Erickson et al., 2010). A study conducted by Erickson et al. (2003) tested the effects of exercise on the hippocampus and found that aerobic exercise training increases the size of the anterior hippocampus and overall hippocampal volume by two percent, which are both signs of neuogenesis. This shows that exercise training can reverse age related memory loss by one to two years (Erickson et al., 2010). Interestingly, exercise has not been associated with neurogenesis in the olfactory bulb, which suggests that the location of neurogenesis from exercise is specific (Van Praag et al., 2008). Additionally, exercise has been shown to increase BDNF levels in the hippocampus, which seems to be directly related to the enhanced learning and memory processes that are observed following exercise interventions. BDNF is necessary for long-term potentiating, a neural analogue of long-term memory formation, and for the growth of new neurons. It has been shown that serum BDNF levels can be increased following acute bout interventions as well as long-term interventions (Anderson-Hanley et al., 2012; Gold et al., 2003; Hillman et al., 2008).

Previous research has shown that physical activity has the largest effect on executive function (Colcombe & Kramer, 2003). The area of the brain that is associated with executive function is the prefrontal cortex. It has been shown that physical activity activates this region of the brain. Reading and mathematic comprehension examinations have also been shown to activate the prefrontal cortex (Hillman et al., 2008; Maguire, Frith, & Morris, 1999). Therefore, it should follow that people who engage in a combination of physical and mental activity (of certain types) should get increased cognition benefits in the prefrontal cortex.

Several research studies have started to examine the P3 component of ERPs in order to study the effectiveness of exercise. The anterior cingulated cortex (ACC) has been associated with generating the differences in amplitude along with a network of other neural structures. The ACC is part of the brain's limbic system and has connections with multiple brain structures that process cognitive information, in particular executive function (Hillman et al., 2008). Physical activity influences the ACC and the executive processes it mediates. This is a second area of the brain that seems to receive input from both mental and physical exercise, and thus should be more activated in a combination of the two exercises. Research has also found that there are differences in activation in the ACC among fit and unfit individuals. Therefore, there is evidence to support that fitness plays a role in cognitive functioning.

The Current Study

The current study attempts to provide evidence to support the later theory on neurogenesis, where interactive exercise leads to additional cognitive benefits due to the exercises activating the same brain regions and neuronal tracks. Currently, there are no measures that can test this theory directly, however this study will use evidence from neuropsychological executive function tests to compare the scores of participants who engage in interactive and synchronous exercise. This will aid in understanding if there exists an added cognitive benefit from two exercises being done interactively.

The purpose of the current study is to tease apart the components of exergaming and analyze the potentially key interactive role between the mental and physical exercise. In particular, the current study investigated if the increase in cognitive functioning from the cybercycle, such as seen in previous work conducted by Anderson-Hanley et al. (2012), might be due to the mental and physical properties being interactive (where action in one affects the other), or if it is enough to have the mental and physical tasks occurring at the same time, thus "synchronized" but unrelated (as when doing a mental task such as reading, while also pedaling). The cybercycle is an example of interactive mental and physical exercise, how fast an individual pedals determines how fast he or she goes in the virtual 3D videogame, while steering determines how he or she stays on track. However, not everyone has access to a cybercycle and part of the aim of this research is to increase exercise participation in the general public. This study hopes to expand the idea of synchronized gaming and exercise to include other forms of independent mental tasks. Thus, the second condition involves traditional exercise with an independent cognitive task. An example of an independent cognitive task would be learning basic Spanish, playing a handheld game, watching an educational television show, or studying for an exam. Previous research conducted by O'Leary et al. (2011) suggests that the mental exercise aspect cannot be too challenging or participants lose the aerobic effects of the exergame. The current study selected an educational television show on the planet Mars as the independent cognitive task. This independent exercise is of minimal difficulty, which, based on previous research, should not take away from the aerobic benefits, but might still add an additional cognitive benefit due to the need to cognitively process the information due to a pre-announced post-test on the topic (Maillot et al., 2011). Also, this mental task is educationally relevant and thus may have a better degree of transfer into other areas of cognitive function (Maillot et al., 2011). Furthermore, it simulates what naturally occurs in many exercise environments where exercisers seek out ways to cope with exercise and choose to watch TV. Thus, in this "synchronized" condition actions take in physical exercise do not affect actions on the screen as in the exergame. Therefore, the two types of exercise are independent from one another, but in synch (simultaneous) versus in tandem (Evers et al., 2011; Lichtman & Poser, 1983;

Haddock et al., 2012), which has been studied previously. The problem with previous tandem studies is that the researchers often cannot control for dose effects and the intervention periods can vary between conditions. This study will focus on synchronous exercise, which controls for dosage. This study will assess if the mere synchronous combination of mental and physical exercise improves brain functioning or if there is something special about the interactive effect of the cybercycle. This study will also separate participants by fitness levels to further investigate the role fitness plays in regulating the cognitive benefits participants can gain from acute bouts of exercise (Clarkson-Smith & Hartley, 1989; Colcombe et al., 2006; Hillman et al., 2008; Kamijo et al., 2011; Sherwood & Shelder, 1979; Spirduso, 1975).

Hypotheses:

It is expected that:

1. Executive functioning is expected to improve significantly more from pre-test to post-test in the interactive cybercycle group compared to the synchronous physical and mental exercise group or the mental exercise group.
2. The increased benefit in the interactive cybercycle condition is due to the property of the tasks being done interactively; it requires the participants to actively process both components the entire time thus exerting more cognitive effect, which activates the same neuronal pathways and leads to more enhanced effects (Van Praag, 2008); whereas participants in the synchronous physical and mental exercise condition may only focus their effort on the cognitive component and not exert the same effort on the

physical exercise component, which will not lead to the same enhanced neuronal benefit.

3. Participants who self-identify as being physically fit will receive an increased benefit from the exercise intervention compared to participants who are unfit due to their brains being structurally and functionally better prepared from years of regular physical activity.

METHODS

Participants

The sample (n=30) consisted of undergraduates from a small liberal arts college in the northeastern USA, aged 18-21 years old (mean = 19.67; SD = 0.88). There were twenty-one females and nine males. Four of the participants were Asian, one participant was African-American, one participant was Indian, and the remaining twenty-four participants were Caucasian. All participants' first language was English. Participants were recruited through the college's online system for participants to enroll in research for credit or other reward; also participants were recruited through flyers posted around campus. Participants were compensated with either 1 credit hour of laboratory experience toward their psychology course or $10 cash for participation. The risks of participating in this study were outlined in an informed consent document approved by the Human Subjects Review Board at Union College and signed by each participant.

Design

The design was a randomized between-subjects single factor independent group design. The independent variable was the exercise condition. The three different exercise conditions were: 1) an interactive cybercycle (bike with videogame), 2) synchronous physical and mental exercise (a stationary bicycle and an educational television show), or 3) mental exercise only (an educational television show). Participants were randomly assigned to one of the three conditions depending on the order they enrolled in the study. In order to randomize the sample, I had put thirty sheets of paper into a hat; ten with the number one, ten with the number two, and ten with the number three. I would draw a number out of the hat before each participant's testing session, and that number determined the exercise condition they were assigned to. The participants in the two exercise conditions both completed a twenty minute acute exercise bout on an Expresso S3R Recumbent Bike (Interactive Fitness Holdings LLC). The third condition (mental exercise only) watched twenty minutes of the educational television show, but without physical activity. Participants in the synchronous mental and physical exercise and also the mental exercise only condition completed a brief five-question paper and pencil quiz on the educational program. To ensure that the participants paid attention to the television program they were cued about this quiz in the beginning of the exercise session. To keep time and the task consistent, the interactive cybercycle condition completed a five-question paper and pencil post-exercise questionnaire. This quiz was different than the quiz on the television show in the synchronous condition; this quiz contained questions that pertained to the virtual course and virtual participants. The dependent variable was executive function, which was measured by paper and pencil neuropsychological tests that included: Color Trails IIA and IIB, Stroop Version 1 and Stroop Version 2, and Backward Digit Span Version 1 and Digit Span Backwards Version 2.

Measures

Color Trails 2 (D'Elia, L.F. & Satz, P., 1996): Color Trails 2 was administered pre and post exercise to assess executive function. The two-week test-rest reliability for Color Trails is acceptable to high (0.79) (Strauss, Sherman, & Spreen, 2006). In addition, there are high correlations between various forms (>0.80) (Strauss, Sherman, & Spreen, 2006). The pre-test forms were: Color Trials 1A and Color Trials 2A. The post-test forms were: Color Trails 1B and Color Trails 2B. Both forms are comprised of twenty-five items. The forms A and B were used to ensure there were no practice effects gained in the post-exercise test. Color Trials is composed of two parts; there is a Color Trails 1 and a Color Trails 2. Color Trials 1 is completed first. In this part, the participant is asked to connect the colored circles in increasing order by going from one, to two, to three, and so on, until they reached the end. The participants were instructed to work as quickly as possible without moving their hand from the paper. After Color Trails 1 was completed successfully, participants were asked to complete Color Trails 2. Color Trails 2 assess executive function, by having the participant connect the colored dots in the correct order, however they also had to alternate between the pink colored circles and the yellow colored circles each time. There were fifty colored blocks on the page in Color Trails 2, however participants must only correctly connect twenty-five; this allows for the executive function to be assessed. Participants were again instructed to work as quickly as possible without taking their hand off the paper. If a mistake was made on either Color Trails 1 or Color Trails 2, the participant was instructed to go back to the correct colored circle and continue from there. The test is scored by how much time it takes to complete; thus the lower the score, the better the performance.

Stroop Task C: Prosper version- 40 items (Van der Elst, 2006): The Stroop Task was administered consistent with the standard protocol with having Stroop A completed first, followed by Stroop B, and Stoop C. The Stroop test is one of the oldest and most widely used assessments in neuropsychology. Reliability coefficients are high among the three parts of the test, 0.90, 0.83, and 0.91 for A, B, and C respectively (Strauss, Sherman, & Spreen, 2006). The reliability of alternate forms was 0.82 (Strauss, Sherman, & Spreen, 2006). Stroop A is comprised of a chart of one practice line and four test lines with different colored blocks. The order of colors is random and the colors that were used were red, blue, and green. The practice line was used to control for any conditions that would prevent the participant from completing the task accurately, such as color blindness. There were ten different colored blocks per line; thus having a total of forty items per task. The participant was told to complete the task as quick as possible. If a mistake was made the examiner was instructed to circle the wrong item and factor an additional time in when scoring the task. Stroop B is administered the same way as Stroop A, however instead of having there be colored blocks there were the names of the color in black ink. Stroop C accesses the executive function aspect of the brain, because it has the names of the colored words in the incorrect colored ink. For example, the color blue would be in red ink. The participant is instructed to say the color of the ink, and ignore the word. This is known as the interference trial, because reading is an automatic process and thus participants will read the name of the word instead of the color. All three of the tests are scored by the amount of time it takes to complete, thus the lower the score the better the performance. There is an alternate version of all three of the tests that was administered post-exercise to control for any practice effects.

Digit Span Backwards (Lezak, Howieson, Loring, Hannay, & Fischer, 2004; Strauss, Sherman, & Spreen, 2006): The digit span test was administered by having participants first complete the Digits Forward and then the Digits Backward, which is standard procedure. There was an alternate form used for the post-test to prevent practice effects. Digits Forward required participants to repeat a string of digits of increasing length in the forward direction, which is a measure of attention and was not of particular interest in this study. For example, the instructor would say “5-8-2”, and the participant would have to repeat the same three numbers in the same order “5-8-2”. The participant would have two trials for each length of numbers. If the participant got at least one of the trials correct, the instructor moved on to the next length of digits. The test is comprised of eight trials from a string of two numbers to a string of nine numbers. The test-retest reliability coefficients range from 0.66 to 0.89 depending on the interval length and subjects’ age (Lezak et al., 2004). The test was scored by recording a one if the trial was correct and a zero if the trial was incorrect. The forward total can range from zero to sixteen. Digits Backward was administered after, which assessed executive function. The test was set up in the same format as Digits Forward, however there were only fourteen trials, with the string of numbers starting at two and ending at eight. For example, the instructor would say, “9-7-2-3”, and the participant would have to say, “3-2-7-9”. The Digits Backward total ranged from zero to fourteen. The Total Score Ranged from zero to thirty. Therefore, the higher the score on each of the test indicates a better performance.

Demographic Questionnaire: A two-page questionnaire was adapted by the researcher off of a standard demographic form used in prior research in our lab. The demographic form assessed basic information about the participant such as: age, gender, handedness, ethnicity, athletic involvement, etc. The form further collected basic medical history information such as any: loss of consciousness, seizures, stroke/brain infections, toxic exposure, etc. The form also monitored substances ingested in the past twelve hours such as: caffeine, ADHD stimulant medication, alcohol, or other. These variables were important to document in order to characterize the sample and they were used to rule out possible unexpected third variable impacts.

Exercise History Questionnaire (McAuley et al., 2011): The exercise history questionnaire was used to put a numerical number to level of physical activity each participant regularly engaged in. The questionnaire required participants to self-report their level of physical activity on a 5-point scale (level 1 = inactive or little activity other than usual daily activities, level 5 = participate in aerobic exercises at a comfortable pace for over 3 hours per week). This was later used to separate participants who were deemed physically fit (level 4 through level 5) and physically unfit (level 1through level 3). Participants were also required to identify the types of activities they engaged in. The types of activity included: strength/resistance exercise, flexibility training/exercise, stamina and endurance exercise, and balance exercise. The questionnaire further asked for their exercise intensity and the participant’s reasons for exercising.

Calculating Target Heart Rate: The participant's target heart rate was calculated using the Karvonen equation (Karvonen et al., 1957). This equation required the instructor to first obtain the resting heart rate of the participant by having them hold onto the handlebars on each side of the cybercycle/stationary bicycle. The resting heart rate and age of the participant were needed to calculate target heart rate. The target heart was used so participants maintained an exercise intensity equal to 60% of their heart rate reserve during the twenty-minute acute exercise bout. This was used to ensure participants were getting the full effect of the exercise intervention.

Target Heart Rate = [(220-age) – (Resting Heart Rate)] x 60% + Resting Heart Rate

Exercise Performance Data Sheet: the experimenter designed this data sheet to monitor heart rate over the course of the acute exercise bout. The experimenter recorded the heart rate of the participant every minute after the five-minute warm-up was completed. At the end of the acute exercise the maximum and average power, speed, and heart rate was recorded. The total distance was also recorded for each participant.

Educational Television Show Questionnaire: this questionnaire was designed by the experimenter and only completed in the second and third exercise conditions. This was a five-question assessment to ensure that the participant paid attention to the educational television program. One of the questions read, "Since there is no

Oxygen on Mars, what is the air made of?" The questions were simple enough that if the participant engaged in the educational television program, they would be able to answer the questions correctly. Each question was scored by either a zero or one, (0 = not correct, 1 = mostly correct). If the participant got three out of five questions correct their data was kept in the sample.

Post-Exercise Questionnaire: the experimenter designed this questionnaire and it was only administered to participants in exercise condition one. This questionnaire acted as a filler to keep the time and forms consistent in all three conditions. This questionnaire followed the same format as the *Educational Television Show Questionnaire,* which consisted of five short questions. One of the questions read, "Did you find this kind of interactive exercise more enjoyable than a standard bike would be?". All participants completed the questionnaire, and there was no scoring related to their answers.

Procedures

The intervention period was one hour; the exercise portion of this study consisted of a twenty-minute acute exercise bout. Participants were lead into the Neuropsychology Healthy Aging Lab where the study was conducted. Participants were randomly assigned to one of three exercise conditions and given an ID number prior to their arrival. All participants were greeted at the lab by the experimenter who was following a script to ensure consistency across participants while giving instructions and administering the neuropsychological evaluations. Participants signed an Informed Consent Form acknowledging their participation in the study was part of a student research project and their results would remain confidential. Participants completed a brief Demographic Questionnaire that was developed by the researcher and an Exercise History Questionnaire developed by McAuley et al. (2011). Participants then completed the pre-neuropsychological evaluation, which consisted of Color Trails IA & IIA, Stroop A, B, & C, and Digit Span Forward and Backward in that order. Participants were given a brief explanation of the measures that were being used and directions were read out loud to the participant for each test (Appendix A). Data was collected through paper and pencil questionnaires for Color Trails IA & IIA, Stroop A, B, & C, and Digit Span Forward and Backward. Following the pre-evaluations, participants were lead into the exercise room to complete the experimental manipulation.

Participants in the first condition were required to ride the cybercycle for twenty minutes. The cybercycle was connected to a virtual reality track such as found on many college campuses; the participant pedaled and turned the handlebars to control their avatar (character) on the track (the interactive condition). Participants in the second condition were required to ride the same bike in the stationary mode for twenty minutes while they watched an educational television show titled, *The Universe: Season 1: Episode 2-Mars: The Red Planet* (the sync mental and physical exercise condition). The third condition watched the same educational television show for twenty minutes without engaging in any physical exercise (the mental exercise only condition). The participants' resting heart rate was measured through the built-in heart rate monitor of the Expresso Bike (conditions one and two).

A target heart rate that was unique to each participant was calculated using the Karvonen equation (Karvonen et al., 1957; McAuley et al., 2011). Participants were instructed to exercise at their target heart rate during the twenty minute acute exercise bout. The experimenter stood outside the exercise room and monitored the participant's heart rate by taking recordings every minute through a two-way mirror. After the exercise session the participant's distance, average power, maximum power, average speed, maximum speed, average heart rate, and maximum heart rate was recorded. Participants were given a glass of water and then completed either the *Educational Television Questionnaire* (conditions two and three) or the *Post-Exercise Questionnaire* (condition one). Participants then completed their post-neuropsychological evaluation, which consisted of the same tests as the pre-evaluation in the same order. All the tests in the post-evaluation were alternate forms to control for practice effects. Participants were debriefed and compensated for their participation in this exercise study.

Statistical Analysis

Data collected was analyzed using Microsoft Excel and the Statistical Package for the Social Sciences (SPSS v. 12.0). Preliminary analyses were conducted in Microsoft Excel. Repeated Measures ANOVAs and paired-samples t-tests with Tukey's HSD correction were conducted to evaluate any differences between the exercise conditions for the primary dependent variable specified in the hypotheses above.

RESULTS

There were thirty participants who completed the study. There were nine males and twenty-one females with a mean age of 19.67 (*SD* = 0.88). Twenty-four participants were Caucasian, one participant was African, four participants were Asian, and one participant was Indian. Seven subjects were left-handed and twenty-three were right handed. The mean year in college was 2.2 (*SD* = 1.03); where 1 represented freshman, 2 represented sophomore, 3 represented junior, and 4 represented senior. The interactive cybercycle condition was comprised of three left-handed participants and seven right-handed participants. The synchronous physical and mental exercise condition was comprised of ten right-handed participants. The mental exercise only condition was comprised of four left-handed participants and six right-handed participants. There were twenty-three participants who completed the exercise history questionnaire with a level of four or five and were deemed fit. The remaining seven participants completed the exercise history questionnaire with a level of three or below and were deemed unfit. Nine of the fit participants were in the interactive cybercycle condition. Seven of the fit participants were in the synchronous physical and mental exercise condition. Seven of the fit participants were in the mental exercise only condition. The demographic characteristics of the participants are represented in Table 1. The average pre-test and post-test scores are recorded in Table 2.

Heart rate was recorded for the twenty participants who were randomly assigned to the two physical and mental exercise conditions. Eighteen out of the twenty participants reached their target heart rate, and the remaining two participants were within ten beats-per-minute (Table 3). Heart rate was not recorded for the ten participants who were in the mental exercise only condition. The physiological data for the twenty participants whom participated in one of the two physical exercise conditions is recorded in Table 3. The differences between the two conditions on physiological measures were all non-significant, as confirmed by paired t-tests (Table 3). Physiological data for the sixteen participants who were physically fit and in the two physical exercise conditions is characterized in Table 4. The differences between the two conditions were all non-significant, as performed by paired t-tests (Table 4).

Comparing The Effect of Exercise Condition on Executive Function

Multivariate tests showed that the effect of exercise condition on executive function was not significant, $F(6,50) = .37$, $p = 0.89$. The univariate tests were still examined due to the nature of the tests used in this study (various aspects of executive function vs. a single construct). It was taken into account that the more statistical tests that were performed, the error rate increases; however, for the purpose of this study univariate tests were examined for the different variables of interest.

The effect of exercise condition on executive function as measured by Color Trails 2 was not significant, $F(2,27) = 1.19$, $p = 0.32$, participants in the interactive cybercycle condition ($M = -5.5$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -6.9$), and to the mental exercise only condition ($M = 0.5$; Table 5). The negative mean indicates that the participants performed faster on the post-test. Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 6).

The effect of exercise condition on executive function as measured by Stroop C was not significant, $F(2,27) = 0.04$, $p = 0.96$, participants in the interactive cybercycle condition ($M = -5.3$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -5.6$), and in the mental exercise only condition ($M = -5.3$; Table 5). The negative mean indicates that the participants performed faster on the post-test. Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 6).

The effect of exercise condition on executive function as measured by Digit Span Backwards was not significant, $F(2,27) = 0.12$, $p = 0.90$, participants in the interactive cybercycle condition ($M = 0.7$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = 0.8$), and in the mental exercise only condition ($M = 0.5$; Table 5). Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually; however the results did indicate a slight trend toward significance between the interactive cybercycle condition and the synchronous physical and mental exercise condition, $p = 0.06$ (Table 6).

To get a pure representation of executive function, we subtracted performance on Color Trails 1 from Color Trails 2 (Strauss, Sherman, & Spreen, 2006). Color Trails 1 does not require any executive function; it just represents how fast a participant can connect the numbers in increasing order. These scores were deemed as “Color Trails Difference”. The same was done for the Stroop Test, where Stroop B was subtracted from Stroop C. Stroop B is the reading of words, which is an automatic processing; therefore to get pure executive function this was factored out. These scores were known as "Stroop Difference". There was not a significant effect of exercise condition on the Color Trails Difference scores, $F(2,27) = 0.69$, $p = 0.51$, participants in the interactive cybercycle condition ($M = -1.6$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = 0.6$), and in the mental exercise only condition ($M = 5.4$) (Table 5). The negative mean indicates that the participants performed faster on the post-test. There was not a significant effect of exercise condition on the Stroop Difference scores, $F(2,27) = 0.04$, $p = 0.96$, participants in the interactive cybercycle condition ($M = -4.6$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -4.5$), and in the mental exercise only condition ($M = -5.0$) (Table 5). The negative mean indicates that the participants performed faster on the post-test. Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 6).

The Effect of Exercise Condition on Executive Function With Only Fit Participants

The effect of exercise on executive function was hypothesized to depend on a factor of fitness. To test this hypothesis fitness was used as a covariate; however the effects were nonsignificant, $F(2,26) = 0.61$, $p = 0.55$. Since the covariate of fitness was nonsignificant, the participants who were deemed unfit were dropped from the analysis and the effects of exercise on executive function was examined with only fit participants.

There were nine participants in the interactive cybercycle condition, seven participants in the synchronous physical and mental exercise condition, and seven participants in the mental exercise only condition. The effect of exercise condition on executive function was not significant with only the fit participants, $F(6,36) = 0.654$, $p = 0.69$. The univariate tests were still examined due to the nature of the tests used in this study (various aspects of executive function vs. a single construct). It was taken into account that the more statistical tests that were performed, the error rate increases; however, for the purpose of this study univariate tests were examined for the different variables of interest.

The effect of exercise condition on executive function as measured by Color Trails was not significant, $F(2,20) = 1.78$, $p = 0.20$, participants in the interactive cybercycle condition ($M = -2.1$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -8.6$), and in the mental exercise only condition ($M = 2.6$).The negative mean indicates that the participants performed faster on the post-test. Participants in the mental exercise only condition were the only group that got slower on the post-test (Table 5). Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 7).

The effect of exercise condition on executive function as measured by Stroop C was not significant, $F(2,20) = 0.07$, $p = 0.93$, participants in the interactive cybercycle condition ($M = -7.2$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -5.7$), and in the mental exercise only condition ($M = -5.2$). The negative mean indicates that the participants performed faster on the post-test (Table 5). Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 7).

The effect of exercise condition on executive function as measured by Digit Span Backwards was not significant, $F(2,20) = 0.71$, $p = 0.51$, participants in the interactive cybercycle condition ($M = 1.0$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = 0.9$), and in the mental exercise only condition ($M = 0.0$) (Table 5). Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 7).

The pure executive function scores were looked at with only using the fit participants. There was not a significant effect of exercise condition on the Color Trails Difference scores, $F(2,20) = 2.51$, $p = 0.11$, participants in the interactive cybercycle condition ($M = 3.6$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -4.6$), and in the mental exercise only condition ($M = 9.6$). The negative mean indicates that the participants performed faster on the post-test (Table 5). There was not a significant effect of exercise condition on the Stroop Difference scores, $F(2,20) = 0.02$, $p = 0.98$, participants in the interactive cybercycle condition ($M = -6.6$) did not improve more in performance compared to the synchronous physical and mental exercise condition ($M = -4.9$), and in the mental exercise only condition ($M = -5.3$) (Table 5). The negative mean indicates that the participants performed faster on the post-test. Follow up Tukey Post-Hoc tests show that there were no significant differences in executive function scores when comparing each group individually (Table 7).

The Effect of Combined Physical and Mental Exercise on Executive Function

There were twenty participants in the groups that had a combination of physical and mental exercise; which included the interactive cybercycle condition and the synchronous physical and mental exercise condition. There were ten participants in the mental exercise only condition. The purpose of combining the two exercise groups was to look at the general benefits of completing two exercises at one time versus only one type of exercise. This hopes to provide evidence that any combination of physical and mental exercise would lead to better cognitive benefits than just one exercise alone. The test that has seemed to provide the most accurate measurement of executive function in this study was Color Trails Difference scores. The Color Trails Difference scores was the only test we used to evaluate this group of participants.

The effect of exercise condition on executive function measured by the Color Trails Difference scores was nonsignificant, $F(1,28) = 1.28$, $p = 0.27$; such that participants in the combined physical and mental exercise condition ($M = -0.49$) did not increase their performance on the executive function test significantly more than the participants in the mental exercise only condition ($M = 5.40$). The negative mean indicates that the participants performed faster on the post-test (Table 8).

Since the results were not significant for all participants, the unfit participants were dropped from the analysis. There were sixteen participants in the group that had a combination of physical and mental exercise. There were seven participants in the mental exercise only condition. There was a significant effect of combined exercise on executive function as measured by the Color Trails Difference scores, $F(1,21) = 4.98$, $p < 0.05$, such that participants who had both physical and mental exercise ($M = -2.9$) improved in performance more than participants who only had mental exercise ($M = 9.6$) (Table 8).

The negative mean indicates that the participants performed faster on the post-test. The graph of the results can be viewed in Figure 1. The significant results were not obtained when the fitness variable was a covariate, $F(2,26) = 1.15$, $p = 0.29$.

Comparing The Physiological Characteristics Between The Physically Active Conditions

There were twenty participants who were randomly assigned to one of the two physical exercise conditions. Ten participants were randomly assigned to the interactive cybercycle condition and ten participants were randomly assigned to the synchronous physical and mental exercise condition. Statistical tests were completed to see if there were any significant physiological differences between the conditions that could have accounted for any difference in executive function outcomes.

The first physiological characteristic that was examined was average heart rate. The effects of exercise condition on executive function as measured by Color Trails with heart rate average as a covariate was nonsignificant, $F(1,17) = 0.04$, $p = 0.84$; such that there were no differences between the average heart rate in the interactive cybercycle condition compared to the synchronous physical and mental exercise condition. When measured by the Stroop C, the results were also nonsignificant, $F(1,17) = 0.01$, $p = 0.93$. The effects of exercise condition on executive function was further measured using Digit Span Backwards and average heart rate as a covariate; the results were non-significant, $F(1,17) < .001$, $p = 0.98$. The effects of exercise on executive function were nonsignificant when measured using the Color Trails Difference scores and average heart rate as a covariate, $F(1,17) = 0.10$, $p = 0.75$. Similarly, using the Stroop Difference scores and average heart rate as a covariate the results were nonsignificant, $F(1,17) = 0.04$, $p = 0.85$.

The second physiological characteristic that was examined was average speed. The effects of exercise condition on executive function as measured by Color Trails with average speed as a covariate was nonsignificant, $F(1,17) = 0.30$, $p = 0.59$; such that there was no difference between the average speed in interactive cybercycle condition compared to the synchronous physical and mental exercise condition. When measured by the Stroop C, the results were also nonsignificant, $F(1,17) = 0.00$, $p = 0.99$. The effects of exercise condition on executive function were further measured using Digit Span Backwards and average speed as a covariate; the results were nonsignificant, $F(1,17) = 0.09$, $p = 0.77$. The effects of exercise on executive function was nonsignificant when measured using the Color Trails Difference scores and average speed as a covariate, $F(1,17) = 0.03$, $p = 0.87$. Similarly, using the Stroop Difference scores and average speed as a covariate the results were nonsignificant, $F(1,17) = 0.04$, $p = 0.84$.

The third physiological characteristic that was examined was average power. The effects of exercise condition on executive function as measured by Color Trails with average power as a covariate was nonsignificant, $F(1,17) = 0.17$, $p = 0.68$; such that there was no difference between the average power in the interactive cybercycle condition compared to the synchronous physical and mental exercise condition. When measured by the Stroop C, the results were also nonsignificant, $F(1,17) = 0.01$, $p = 0.92$. The effects of exercise condition on executive function were further measured using Digit Span Backwards and average power as a covariate; the results were nonsignificant, $F(1,17) = 0.03$, $p = 0.87$. The effects of exercise on executive function was nonsignificant when measured using the Color Trails Difference scores and average power as a covariate,

$F(1,17) = 0.05$, $p = 0.82$. Similarly, using the Stroop Difference scores and average power as a covariate the results were nonsignificant, $F(1,17) = 0.02$, $p = 0.90$.

DISCUSSION

Research has shown the benefit of exercise (Colcombe & Kramer, 2003) and exergaming (Anderson-Hanley et al., 2012) on cognition; however, it is still unclear what combination of mental and physical exercise might yield the greatest cognitive benefit. This study attempted to tease apart the components of exergaming to examine the cognitive effects of interactive, synchronized, and mental exercise only on executive function. This study questioned if there was something special about interactive exercises or if a synchronized combination of physical and mental exercise was sufficient to obtain the increased cognitive benefits previously documented. It was hypothesized that interactive exercise would lead to greater cognitive benefits than synchronized or mental exercise alone. Thirty college students enrolled in a single bout exercise intervention and completed a neuropsychological battery of executive function tests pre and post exercise intervention. The present findings extended previous research and found that fit participants can engage in some form of combined exercise (either interactive or synchronized exercise) and obtain greater cognitive benefits that if completing just mental exercise alone.

The initial hypothesis was that the interactive group would improve significantly more on the executive function tests following an acute exercise intervention than the synchronized physical and mental exercise group, or than the mental exercise group (hypothesis 1). It was predicted that this increased benefit in the interactive cybercycle condition would be due to the exercises being interactive, where the participants were forced to actively process both components the entire exercise session, whereas participants in the synchronized condition could allocate more cognitive resources to one exercise and not the other, and in turn not receive the same degree of cognitive benefits (hypothesis 2). Results showed that the group by time interaction for exercise condition and executive function scores was not significant; which led us to reject the first hypothesis. These findings suggest that some form of combined physical and mental exercise is better than mental exercise alone. The results indicate that there is an equal effect between synchronized and interactive exercise, however due to the lack of significance in the multivariate analysis and the use of the small sample size the results may be obscured. More research is needed to clarify if there really is a difference between interactive and synchronized exercise. A larger sample size may reveal if there is a difference, which was not able to be dected here. One possible explanation is that as the mental exercise was relatively effortless in the synchronized condition, it did not take away from the intensity of physical activity, and therefore allowed the participants to actively process both stimuli the entire time. This processing is similar to what was predicted to happen in the interactive condition, which could explain why there was not an observed difference in cognitive function between the two physical exercise conditions. Although the findings did not support the initial hypotheses, further discussion of the present study's results will indicate other significant findings and trends that will lead to further research on the effects of combined physical and mental exercise on executive function.

It was predicted that participants who self-identified as being physically fit would receive an increased cognitive benefit from the exercise intervention, which would lead to a larger improvement on executive function scores (hypothesis 3). This predication that fitness plays a key role in determining cognitive functioning was based on previous research (Chang et al., 2012; Clarkson-Smith & Hartley, 1989; Colcombe et al., 2006; Kamijo et al., 2011; Sherwood & Selder, 1979; Spirduso, 1975). When only fit participants were used in the analysis, the group by time interaction dropped from being clearly nonsignificant ($p = 0.51$) to a value that, while still not significant, may indicate a trend ($p = 0.11$). Previous research has found that the brains of fit individuals have greater connectivity between brain regions (Kamijo et al., 2011). Therefore, the fit participants in the current study could have had greater cognitive benefits than the unfit participants due to the better connections and priming of their neuronal tracks. Another study documented that fit individuals do not need to allocate the same cognitive resources to physical exercise as unfit individuals due to a lifetime of activity and thus fit individuals have more resources to allocate to cognitive engagement (Chang et al., 2012). This could explain why the fit participants were more sensitive to the effects of single bout exercise than the unfit participants.

The study was designed to hold exercise duration and intensity consistent between the two physically active conditions (the cybercycle and the independent physical biking and the educational television show). The study was successful in this respect as heart rate did not differ between exercise conditions and the overall intensity of the exercise was equal to sixty percent of participants' heart rate reserve during the twenty-minute acute exercise bout. If participants incorporated this exercise routine into their daily lives they would meet the CDC's recommended weekly aerobic activity level (Centers for Disease Control, 2011). In addition to the cross-group physiological measure of heart rate, measurements of distance, speed, and power did not differ between exercise conditions. These findings are consistent with prior research that states that exergaming does not take away from the intensity of traditional exercise (Anderson-Hanley et al., 2012; Haddock et al., 2012; Kraft et al., 2011; O'Leary et al., 2011). One limitation of this study was that heart rate was not recorded for participants in the mental exercise only condition. Heart rate was not expected to change from the participant's resting heart rate due to the sedentary nature of the mental exercise and based on prior research, which showed that heart rate did not increase in a seated rest condition (O'Leary et al., 2011). Since heart rate was not recorded for the mental exercise only condition, this study cannot conclude that there is a difference between the intensity of seated mental exercise and the combination of physical and mental exercise; however, such a finding would logically follow.

In a secondary analysis, where the physical exercise conditions were collapsed (this considers both the interactive cybercycle condition and synchronized physical and mental exercise condition), there were notable significant results for the fit participants. The study found that there was a significant group by time interaction as measured by the Color Trails Difference Scores. The Color Trails Difference measure was used to assess the collapsed groups because it is a more sound assessment of executive function and seemed to be the most sensitive test for acute bout exercise. The combined exercise group improved their executive function scores by three seconds on average, whereas the mental exercise group got nine seconds slower following the exercise intervention on average. The purpose of collapsing the two physical exercise conditions was to evaluate if there was a general benefit of combined physical and mental exercise on cognition. This would allow exergaming research to be able to be generalized to all combined physical and mental exercise and therefore it would suggest that perhaps the general public could receive these additional cognitive benefits even if they do not have a cybercycle, but instead by watching educational television while pedaling at the gym or at home.

This study documented a novel finding by teasing apart two important aspects of exercise by examining the separate and interactive effects of physical and mental exercise. This study built upon the results of research conducted by Anderson-Hanley et al. (2012) and looked into what explained the added cognitive benefit of the cybercycle over traditional exercise. Our findings suggest that the added benefits were due to any synchronized exercise routine, where the physical activity produces an enriched environment for the additional cognitive benefits from mental challenges. This suggests that one does not necessarily have to engage in an interactive exercise to get the same increase in cognitive benefits. This is consistent with the first theory proposed by Van Praag (2008), which states that physical exercise prepares the body and the mind for enhanced cognitive function by cell proliferation and cell survival. Other studies have supported this claim that suggests it is the physical activity that allows for the greater allocation of attentional resources to exert over other areas of cognitive function (Best, 2012; Hillman et al., 2008). However, cell proliferation and cell survival is unlikely to occur in a single bout study and the increased cognitive benefit may be consistent with the second theory proposed by Van Praag (2008). A meta-analysis conducted by Chang et al. (2012) looked at several studies (Dietrich 2006; Dietrich and Sparling, 2004) on single bout exercise and found that exercise and cognitive processing require similar neuronal structures and metabolisms, which would also explain why both synchronized and interactive exercise produced stronger cognitive benefits than mental exercise alone.

Previous research determined this by examining the limited and constant metabolic capacity of the brain and how the brain responded to different exercises (Chang et al., 2012; Dietrich, 2006; Dietrich and Sparling, 2004). More research on a large sample size needs to be conducted in order to identify the difference in cognitive benefits from interactive and synchronized exercise.

Contrary to the current study, some mental exercises can activate the same areas of the brain as physical exercise (Hillman et al., 2008; Maguire, Faith, & Morris, 1999). In this case, it would support the claim that it would not matter if the exercises were done interactively or synchronized; as long as they are done at the same time, there should be an increase in brain function in the same area of the brain. Not all mental exercises are the same and thus certain exercises tap into other areas of cognitive function. In this study, the educational television is a passive mental exercise, whereas a videogame is an interactive mental exercise (Best, 2011; O'Leary et al., 2011). The educational television program tapped into memory and learning, rather than purely executive function. This is interesting because memory is linked to the hippocampus, which is where neurogenesis has been known to occur (Erickson et al., 2003; Van Praag et al., 199; Van Praag, 2008). These previous studies have linked physical exercise to neurogenesis in the hippocampus, therefore the combination of the physical exercise and mental challenge used in the current study may have further induced neurogenesis. Follow-up studies should replicate the current method and use neuroimaging to understand how interactive and synchronized exercise impacts the brain in a long-term exercise intervention. Although there are proposed theories and explanations as to why combined exercise has a larger effect than traditional exercise on cognitive function, it is necessary to develop a concrete theory based on empirical evidence.

Unlike previous research (Orosy-Fildes & Allan, 1989), this study found that there were no changes in executive function following acute bouts of mental exercise. Orosy-Fildes and Allan (1989) found that a single bout of videogaming results in a 50ms reduction in reaction time. In contrast, the current study found that participants in the mental exercise condition got slower following the exercise intervention on all tests of executive function except for Stroop C. However, it is still unclear as to what degree of cognitive challenge the participants in the mental exercise condition did experience due to the nature of the task used and there was no explicit measure used in this study to assess this directly. In contrast to the current study, previous studies have used watching television as a control task since it can be thought of as “mind-numbing” (Daley & Maynard, 2003). Since the television program used in this study was educational and had a five-question quiz that followed the intervention, we thought of this task as a mental challenge. However, there could be some factors that the five questions did not quite capture, and further research should assess the degree of mental challenge associated with an educational television program. The results from this study are similar to the study conducted by O’Leary et al. (2011), which found that there was no improvement in reaction time or accuracy following a single bout of videogame play; reaction time was not evaluated in the current study, but the overall concept that there was no improvement in execute function following mental exercise was similar between the two studies. The differences between all three studies could result from the varying neuropsychological tests used and the different aspects of executive function that were examined. O’Leary et al. (2011) used a modified flanker task, which assess inhibitory aspects of executive function. Orosy-Fildes and Allan (1989) used a measure to assess reaction time. This current study used three different executive function tests, which measured working memory (Digit Span Backwards), interference in reaction time (Stroop C), and task switching (Color Trails). Some areas of executive function may be more sensitive to the mental exercise intervention, which could explain the contrasting results between studies.

Strengths

The design of the study is congruent to prior research investigating the effects of exercise on cognitive function. The use of executive function as a dependent variable was based on prior research that suggested that executive function is the main cognitive domain targeted by exercise (Colcombe & Kramer, 2003). The use of the physical activity questionnaire to distinguish between the young adults who were fit and unfit was based on prior research that suggested it was a reliable measure for physical fitness (Kamijo et al., 2011; McAuley et al., 2011). Based on previous studies, the Karvonen equation was used to calculate target heart rate and to ensure participants exercised at an intensity that was recommended by the American College of Medicine and the CDC (Haddock et al., 2012; Karvonen et al., 1957; Kraft et al., 2011; O'Leary et al., 2011). The pre-test post-test design for evaluation of executive function was conducted based on the designs of previous exercise studies (Best, 2012; Evers et al., 2011; Lichtman & Poser, 1983; Maillot et al., 2011; O'Leary et al., 2011). A strength of the current study, that was not seen in previous research, is that the equipment and mental exercise tasks were kept consistent in all conditions. Previous research that tried to tease apart the different aspects of exergaming did not keep the gaming equipment and mental challenge consistent across conditions, which could explain the contrasting results of the studies (Best, 2012). In the current study, an Expresso Bike was used in both physical exercise conditions and the educational television show was used in both conditions that incorporated an independent mental task. The current study built upon the conclusions of previous research (Anderson-Hanley et al., 2012; Best, 2012; Maillot et al., 2011; O'Leary et al., 2011) and revealed that the additional cognitive benefits gained from exergaming could result from simply doing two synchronized exercises. The study suggests that people who are physically fit will gain slightly more benefits from combined exercise, which is consistent with previous work (Clarkson-Smith & Hartley, 1989; Colcombe et al., 2006; Kamijo et al., 2011; Sherwood & Shelder, 1979; Spirduso, 1975). However, the role of fitness is still unclear because a significant effect was only seen in one executive function test and therefore it could have resulted from the escalating error rate from our use of multiple statistical tests. The findings of this study can be applied to real life situations, as people that do not have access to a cybercycle can grab a book, watch educational television, or do Sudoku while physically exercising to receive the added benefits of combined exercise. This study hopes to provide evidence that there are alternatives to traditional exercise that may be more appealing and therefore increase the population's participation in regular physical exercise.

Limitations

There were several possible limitations with the design of the current study that may have impacted the results. One flaw in the design is that the study used a small sample size. A small sample size not only inaccurately represents the population, but it is also more difficult to find significant results. This current experiment eliminated the unfit participants in the secondary analyses of the data, which left only seven participants in the mental exercise condition and sixteen participants in the combined physical and mental exercise collapsed condition. This sample size is even smaller than the original, which makes it difficult to draw conclusions and comparisons in this study. If the sample size was larger it is possible that there would be a significant difference between the three exercise conditions. In addition to the small sample size, there was no pure physical exercise group to use as a comparison. It was decided that a mental exercise group would be used instead of a physical control due to the fact that there is less research on mental exercise and thus there is more to learn. From previous research studies conducted in Doctor Cay Anderson-Hanley's Neuropsychology Healthy Aging Lab, it was already generally accepted that the cybercycle has an increased benefit over traditional exercise alone (Anderson-Hanley et al., 2012). The duration of exercise could have been a limitation in this study. The twenty minute acute bout of exercise may not be sufficient to illustrate the differences between the three exercise conditions. Previous research conducted by Basak et al. (2008) saw effects of videogame play on executive function after a twenty-four hour intervention. This suggests that the intervention period could have been too short to allow for mental exercise benefits to be fully obtained. However, the exercise duration may not have been a limiting factor as previous research has shown that twenty minutes leads to differences in cognitive function (Best, 2012; Chang et al., 2012; O'Leary et al., 2011; Roig et al., 2012). Another possibility is that the independent mental exercise may not have been challenging enough. O'Leary et al. (2011) suggested that if the mental exercise was more challenging than the physical exercise participants would not receive the additional benefits of combined exercise. Due to these finding the educational television show was chosen as the mental exercise task in the current study due to its novice challenge. However, the educational television show may have been too effortless. Future mental exercise research needs to find a moderately challenging task that is somewhere in between educational television and a videogame that consists of variable cognitive control (Basak et al., 2008; Best, 2012; O'Leary et al., 2011).

Concurrent and Future Research

Concurrent research used a different mental exercise task in the synchronized exercise condition that checked if the increased benefits were still equivalent to that of the interactive cybercycle. This tapped into the effects of cognitive challenge and examined if a more challenging mental exercise took away from the physical exercise benefits that were seen in the studies conducted by Best (2012) and O'Leary et al. (2011). This was carried out in a summer research study sponsored by a grant from Union College (Moore, 2012). The mental exercise was changed from an educational television show to a moderately challenging dragon-chase videogame, which was also used in the interactive cybercycle condition. The design was a randomized between-subjects single factor independent group design. The independent variable was the exercise condition that participants were assigned to, which was either the interactive cybercycle or the synchronized physical and mental exercise condition (the stationary bike and dragon-chase videogame (Moore, 2012). The procedure was consistent with the current study, except for the addition of an attentional focus questionnaire. The attentional focus questionnaire was added based on the significant findings found in a thesis study conducted by Nicholas Ranalli (2012), where he found distractions such as music could cause participants to experience dissociative feelings. The videogame could have served as a distraction, as participants may have been more focused on capturing the dragons or getting points than on their feelings of exhaustion from physical activity. Results were significant for the Stroop C executive function measure, where participants in the interactive cybercycle condition had a larger improvement following the single bout intervention than participants in the synchronized physical and mental exercise condition. There was also a significant effect of attentional focus; participants in the interactive cybercycle condition had associative attentional focus, whereas participants in the synchronized physical and mental exercise condition had dissociated attentional focus. One problem in this study was that the majority of participants in the synchronized physical and mental excise condition could not reach their target heart rate calculated by the Karvonen equation (Karvonen et al., 1957; Moore, 2012).

Future research should coach participants into reaching their target heart rate to ensure that they exercise at an intensity equal to sixty-percent of their heart rate reserve. This would allow the researcher to conclude that the increased cognitive benefits in the interactive cybercycle condition are due to the nature of the exercises being interactive, rather than the explanation that the participants in the synchronized condition may not be exercising at a high enough intensity to equally gain the cognitive benefits. Further research should also assess the degree of mental challenge associated with the mental exercise, whether it be watching television or playing a stationary videogame. This would allow us to find the balance between mental exercises being too challenging and not challenging enough. A follow-up study should add two additional conditions, a physical exercise only condition and a mental exercise only condition, to examine the cognitive challenges faced in each exercise alone. This will allow the researchers to better understand the relationship in the brain between interactive and synchronized exercise on cognitive functioning.

Conclusion

As previously mentioned, the purpose of this study was to tease apart the two aspects of the cybercycle to determine if the added cognitive benefit was due to the physical and mental exercises being completed at the same time (synchronous) or the interaction between the exercises. Although the initial hypothesis was not supported, the present findings suggest that there is an added benefit to engaging in both a physical and mental exercise at the same time, and that it may not matter if the exercises are interactive or synchronized. Additionally, this relationship was observed in participants who were physically fit, further suggesting that fitness plays a key factor in determining cognitive function. It was hoped that this research could encourage the use of these accessible and alternative exercise regimens that could be used by the general population. This would not only lead people to live a more active lifestyle, but could also be used to delay or prevent the signs of cognitive decline. The number of new cases of dementia and Alzheimer's disease are rising and combined physical and mental exercise interventions have the potential to help stop this rising epidemic.

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REFERENCES

Anderson-Hanley, C., Arciero, P.J., Brickman, A.M., Nimon, J.P., Okuma, N., Westen, S.C., Merz, M.E., Pence, B.D., Woods, J.A., Kramer, A.F., & Zimmerman, E.A. (2012). Exergaming and Older Adult Cognition. *American Journal of Preventive Medicine,* 42(2), 109-119.

Basak, C., Boot, W.R., Voss, M.W., & Kramer, A.F. (2008). Can Training in a Real-Time Strategy Video Game Attenuate Cognitive Decline in Older Adults?. *Psychology and Aging*, 23(4), 765-777.

Bekris, L.M., Yu, C., Bird, T.D. & Tsuang, D.W. (2010) Genetics of Alzheimer Disease. *Journal of Geriatric Psychiatry and Neurology,* 23(4), 213-227.

Best, J.R. (2012). Exergaming Immediately Enhances Children's Executive Function. *Developmental Psychology,* 48(5), 1501-1510.

Brown, J., Cooper-Kuhn, C.M., Kempermann, G., Van Praag, H. Winkler, J., Gage, F.H., & Kuhn, H.G. (2003). Enriched environment and physical activity hippocampal but not olfactory bulb neurogenesis. *European Journal of Neuroscience*, 17, 2042-2046.

Centers for Disease Control and Prevention. (2010). Physical Activity and Fitness: Chapter 22. *Healthy People 2010 Final Review*. Retried from: http://www.cdc.gov/nchs/data/hpdata2010/hp2010_final_review_focus_area_22.pdf

Centers for Disease Control. (2011). How much physical activity do adults need?. Retrieved from http://www.cdc.gov/physicalactivity/everyone/guidelines/adults.html

Chang, Y.K., Labban, J.D., Gapin, J.I., & Etnier, J.L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453, 87-101.*

Clarkson-Smith, L. & Hartley, A.A. (1989). Relationships Between Physical Exercise and Cognitive Abilities in Older Adults. *Psychology of Aging*, 4(2), 183-189.

Colcombe, S., Erickson, K.I., Scalf, P.E., Kim, J.S., Prakash, R., McAuley, E., Elavsky, S., Marquez, D.X., Hu, L., & Kramer, A.F. (2006). Aerobic Exercise Training Increases Brain Volume in Aging Humans. *Journals of Gerontology*, 61(11), 1166–70.

Colcombe, S. & Kramer, A.F. (2003). Fitness Effects on the Cognitive Function in Older Adults: A Meta-Analytic Study. *Psychological Science*, 14(2), 125-130. doi:10.1111/1467-9280.t01-1-01430.

Daley, A., & Maynard, I. W. (2003). Preferred exercise mode and affective responses in physically active adults. *Psychology Of Sport And Exercise*, 4(4), 347-356. doi:10.1016/S1469-0292(02)00018-3

D'Elia, L.G. Satz, P., Uchiyama, C.L., & White, T. (1996). Color Trails Test. *Odessa FL: Psychological Assessment Resources.*

Descartes, R. (1984). *The Philosophical Writings of Descartes Volume 2.* (J. Cottingham, R. Stoothoff, & D. Murdoch, Trans.) Cambridge, U.K.

Dietrich, A. (2006). Transient hypofrontality as a mechanism for the psychological effects of exercise. *Psychiatry Res.* 145, 79–83.

Dietrich, A. & Sparling, P.B. (2004). Endurance exercise selectively impairs prefrontal-dependent cognition. *Brain Cogn*. 55, 516–524.

Erickson, K.I., Voss, M.W., Prakash, R.S., Basak, C., Szabo, A., Chaddock, L., Kim, J.S., Heo, S., Alves, H., White, S.M., Wojcicki, T.R., Mailey, E., Viera, V.J., Martin, S.A, Pence, B.D., Woods, J.A., McAuley, E., & Kramer, A.F. (2010). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences of the United States of America*, 108(7):3017–22.

Etgen, T., Sander, D., Huntgeburth, U., Poppert, H., Förstl, H., & Bickel, H. (2010). Physical activity and incident cognitive impairment in elderly persons. *Archives of Internal Medicine, 170,* 186 –193. doi:10.1001/ archinternmed.2009.498.

Evers, A., Klusmann, V., Schwarzer, R., & Heuser, I. (2011). Improving cognition by adherence to physical or mental exercise: A moderated mediation analysis. *Aging & Mental Health,* 15(4), 446-455.

Gold, S. M., Schulz, K., Hartmann, S., Mladek, M., Lang, U. E., Hellweg, R., & ... Heesen, C. (2003). Basal serum levels and reactivity of nerve growth factor and brain-derived neurotrophic factor to standardized acute exercise in multiple sclerosis and controls. *Journal Of Neuroimmunology*, 138(1-2), 99-105. doi:10.1016/S0165-5728(03)00121-8

Haddock, B. L., Jarvis, S., Klug, N. R., Gonzalez, T., Barsaga, B., Siegel, S. R., & Wilkin, L. D. (2012). Measurement of energy expenditure while playing exergames at a self-selected intensity. *Open Sports Sciences Journal, 5*, 1–6.

Hillman, C.H., Erickson, K.I., & Kramer, A.F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience*, 9.

Hillman, C.H., Snook, E.M., & Jerome, G.J. (2003). Acute cardiovascular exercise and executive control function. *Int. J. Psychophysiol.,* 48, 307-314.

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *J Gerontol B Psychol Sci,* 64, 356-363.

Kamijo, K., Takeda, Y., & Hillman, C.H. (2011). The relation of physical activity to functional connectivity between brain regions. *Clinical Neurophysiology,* 122, 81-89.

Karvonen, M., Kentala, K., & Mustala, O. (1957). The effects of training heart rate: a longitudinal study. *Ann Med Exp Biol Fenn*, 35, 307-315.

Kraft, J. A., Russell, W. D., Bowman, T. A., Selsor III, C. W., & Foster, G. D. (2011). Heart rate and perceived exertion during self-selected intensities for exergaming compared to traditional exercise in college-age participants. *The Journal of Strength & Conditioning Research, 25*(6), 1736.

Lezak, M.D., Howieson, D.B., Loring, D.W., Hannay, H.J., & Fischer, J.S. (2004). Neuropsychological Assessment *(4th ed.)*. New York, NY: Oxford University Press.

Lichtman, S. & Poser, E.G. (1983). The Effects of Exercise on Mood and Cognitive Functioning. *Journal of Psychosomatic Research*, 27(1), 43-52.

Maguire, E. A., Frith, C. D., & Morris, R. M. (1999). The functional neuroanatomy of comprehension and memory: The importance of prior knowledge. *Brain: A Journal Of Neurology,* 122(10), 1839-1850. doi:10.1093/brain/122.10.1839

Maillot, P., Perrot, A., & Hartley, A. (2011). Effects of Interactive Physical-Activity Video-Game Training on Physical and Cognitive Function in Older Adults.

Psychology and Aging. Advance online publication. doi: 10.1037/a0026268

McAuley, E., Szabo, A.N., Mailey, E.L., Erickson, K.I., Voss, M., White, S.M., Wójcicki, T.R., Gothe, N., Olson, E.A., Mullen, S.P., & Kramer, A.F. (2011). Non-exercise estimated cardiorespiratory fitness: Associations with brain structure, cognition, and memory complaints in older adults. *Mental Health and Physical Activity,* 4, 5-11.

Moore, C. (2012). *Cybercycling For Cognitive Health: The Effects of Interactive and Simultaneous Exercise on Executive Function*. Unpublished manuscript. Union College, Schenectady, NY

O'Leary, K. C., Pontifex, M. B., Scudder, M. R., Brown, M. L., & Hillman, C. H. (2011). The effects of single bouts of aerobic exercise, exergaming, and videogame play on cognitive control. *Clinical Neurophysiology*, 122(8), 1518-1525. doi:10.1016/j.clinph.2011.01.049

Orosy-Fildes, C. & Allan, R.W. (1989). Psychology of computer use: XII. Videogame, play: human reaction time to visual stimuli. *Percept Mot Skills*, 69, 243-247.

Plassman, B.L., Langa, K.M., Fisher, G.G., Heeringa, S.G., Weir, D.R., Ofestedal, M.B., Burke, J.R., Hurd, M.D., Potter, G.G., Rodgers, W.L., Steffens, D.C., Willis, R.J., Wallace, R.B. (2007). Prevalence of Dementia in the United States: The Aging, Demographics, and Memory Study. *Neuroepidemiology*, 29, 125-132. doi:10.1159/000109998.

Pontifex, M.B., Hillman, C.H., Fernhall, B., Thompson, K.M., & Valentini, T.A. (2009). The Effect of acute aerobic and resistance exercise on working memory. *Med Sci Sports Exerc,* 41, 927-934.

Ranalli, N. (2012). *Exercise Effort, Exertion and Enjoyment: The Effects of Music and Virtual Reality*. Unpublished manuscript.

Robbins, T. W. (2000). Chemical neuromodulation of frontal-executive functions in humans and other animals. *Experimental Brain Research, 133,* 130 –138. doi:10.1007/s002210000407

Roig, M., Skriver, K., Lundbye-Jensen, J., Kiens, B., & Nielsen, J.B. (2012). A Single Bout of Exercise Improves Motor Memory. PLoS ONE 7(9): e44594, doi: 10.1371/journal.pone.0044594.

Sherwood, D.E. and Selder, D.J. (1979). Cardiorespiratory health, reaction time and aging. *Medicine and Science In Sports*, 11 (2), 186-189.

Spirduso, W.W. (1975). Reaction and Movement Time as A Function of Age and Physical Activity. *Journal of Gerontology,* 30(4), 435-440.

Strauss, E., Sherman, E.M.S., & Spreen, O. (2006). *A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary (3rd ed.)*. New York, NY: Oxford University Press.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta. Psychologica*, 112(3), 297-324. doi:10.1016/S0001-6918(02)00134-8

Van der Elst (2006). The Stroop Version 1 40 items and The Stroop Version 2 Alternate Form 40 items.

Van Praag, H. (2008). Neuogenesis and exercise: past and future directions. *Neuromolecular Medicine*, 10(2), 128-40.

Van Praag, H., Kempermann, G., & Gage, F.H. (1999). Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. *Nature*

Neuroscience, 2(3).

Table 1. Neuropsychological and Demographic Characteristics

Mean (SD) unless otherwise indicated				**p values**	**p values**	**p values**
	Condition 1: Interactive Cybercycle (*n* = 10)	**Condition 2: Synchronized Physical and Mental Exercise (*n* = 10)**	**Condition 3: Mental Exercise Only (*n* = 10)**	**Cond. 1 v. Cond. 2**	**Cond. 1 v. Cond. 3**	**Cond. 2 v. Cond. 3**
Age, years	19.5 (0.85)	19.8 (0.67)	19.7 (1.16)	0.38	0.67	0.81
Females (n)	8	8	5			
Males (n)	2	2	5			
Years in College	1.9 (0.88)	2.4 (1)	2.1 (1.10)	0.24	0.66	0.53
Medical Factors						
Height, inches	66.5 (4.06)	65.6 (3.31)	67.9 (4.20)	0.59	0.46	0.19
Weight, lbs	143.8 (35.86)	132.2 (29.27)	157.7 (32.7)	0.44	0.38	0.08
Loss of Consciousness	0.2 (0.42)	0.2 (0.42)	0 (0)	1.00	0.15	0.15
Seizures	0 (0)	0 (0)	0.1 (0.32)	1.00	0.33	0.33
Stroke/ Brain Infections	0 (0)	0 (0)	0 (0)	1.00	1.00	1.00
Toxic Exposure	0 (0)	0 (0)	0 (0)	1.00	1.00	1.00
Substances within 12 hours						
Caffeine	0.4 (0.52)	0.4 (0.52)	0.5 (0.53)	1.00	0.67	0.67
ADHD Medication	0.2 (0.42)	0.1 (0.42)	0 (0)	0.56	0.15	0.33
Alcohol	0.2 (0.42)	0 (0.42)	0.1 (0.32)	0.15	0.56	0.33
Other	0 (0)	0 (0)	0 (0)	1.00	1.00	1.00
Fitness Level						
Level of Activity (1-5)	4.4 (1.27)	3.9 (0.42)	3.7 (1.34)	0.38	0.25	0.73
Fit	0.9 (0.32)	0.7 (0.42)	0.7 (0.48)	0.29	0.29	1.00

Table 2. Pre-test and Post-test Executive Function Scores

Pre-test Executive Function Scores						
Color Trails II-A, seconds	56.1 (17)	57.0 (16.61)	57.3 (12.6)	0.90	0.86	0.97
Stroop C, seconds	36.2 (7.74)	31.5 (3.19)	35.9 (6.68)	0.09	0.91	0.08
Digit Span Backwards, string of numbers	6.2 (2.3)	8.2 (2.3)	6.9 (1.85)	0.07	0.46	0.18
Color Trails II-A Difference Score	32.3 (12.39)	27.0 (15.25)	29.6 (11.31)	0.41	0.62	0.67
Stroop Difference Score	19.7 (6.18)	15.1 (3.95)	19.5 (5.47)	0.07	0.93	0.06
Post-test Executive Function Scores						
Color Trails II-B, seconds	50.6 (12.80)	50.1 (10.16)	57.8 (12.51)	0.93	0.22	0.15
Stroop C alt., seconds	31.0 (7.92)	25.8 (3.36)	30.6 (6.08)	0.08	0.91	0.04
Digit Span Backwards alt., string of numbers	6.9 (1.73)	9.0 (2.36)	7.4 (1.90)	0.04	0.55	0.11
Color Trails II-B Difference Score	30.7 (9.16)	27.6 (9.56)	35.0 (12.45)	0.48	0.39	0.16
Stroop Difference Score	15.0 (5.88)	10.6 (3.87)	14.5 (6.74)	0.06	0.84	0.13

Table 3. Physiological Characteristics of Participants in Physical Exercise Conditions

	Mean (SD)	**Mean (SD)**	
Physiological Measures	**Condition 1: Interactive Cybercycle (*n* = 10)**	**Condition 2: Synchronized Physical and Mental Exercise (*n* = 10)**	**p value**
Resting Heart Rate (bpm)	77.2 (14.64)	81.7 (9.76)	0.43
Target Heart Rate (bpm)	151.2 (6.10)	153.2 (4.42)	0.38
Average Heart Rate (bpm)	143.7 (8.68)	147.0 (16.08)	0.57
Maximum Heart Rate (bpm)	160.6 (8.37)	164.4 (16.49)	0.52
Distance (miles)	3.6 (0.46)	3.3 (0.45)	0.23
Average Power (watts)	103.2 (32.67)	93.4 (28.68)	0.49
Maximum Power (watts)	287.1 (86.46)	276.5 (83.72)	0.78
Average Speed (mph)	14.1 (1.90)	13.0 (1.74)	0.17
Maximum Speed (mph)	17.4 (2.89)	17.0 (2.73)	0.77

Table 4. Physiological Characteristics of Fit Participants in Physical Exercise Conditions

	Mean (SD)	**Mean (SD)**	
Physiological Measures	**Condition 1: Interactive Cybercycle (*n* = 9)**	**Condition 2: Synchronized Physical and Mental Exercise (*n* = 7)**	**p value**
Resting Heart Rate (bpm)	84.0 (15.45)	82.4 (11.69)	0.69
Target Heart Rate (bpm)	154.1 (6.45)	154.0 (5.17)	0.50
Average Heart Rate (bpm)	144.7 (8.53)	141.7 (14.96)	0.89
Maximum Heart Rate (bpm)	162.0 (8.55)	160.6 (16.46)	0.95
Distance (miles)	3.4 (0.46)	3.3 (0.48)	0.10
Average Power (watts)	90.0 (32.77)	90.9 (31.76)	0.20
Maximum Power (watts)	243.3 (88.73)	268.9 (94.29)	0.20
Average Speed (mph)	13.4 (1.91)	12.8 (1.91)	0.08
Maximum Speed (mph)	17.0 (2.98)	16.9 (3.14)	0.32

Table 5. Neuropsychological Outcomes Following The Acute Exercise Bout

	Mean	**Mean**	**Mean**	
	Condition 1: Interactive Cybercycle	**Condition 2: Synchronized Physical and Mental Exercise**	**Condition 3: Mental Exercise Only**	**P values**
All Participants No Covariates	***n* = 10**	***n* =10**	***n* = 10**	
Color Trails	-5.5	-6.9	0.5	0.32
Stroop	-5.3	-5.6	-5.3	0.96
Digit Span	0.7	0.8	0.5	0.90
Color Trails Difference Scores	-1.6	0.6	5.4	0.51
Stroop Difference Scores	-4.6	-4.5	-5.0	0.96
Used Only Fit Participants	***n* = 9**	***n* = 7**	***n* = 7**	
Color Trails	-2.1	-8.6	2.6	0.20
Stroop	-7.2	-5.7	-5.2	0.93
Digit Span	1.0	0.9	0.0	0.51
Color Trails Difference Scores	3.6	-4.6	9.6	0.11
Stroop Difference Scores	-6.6	-4.9	-5.3	0.98

Table 6. Tukey Post-Hoc Tests for Differences in Executive Function

Executive Function Measurement	Condition 1 v. Condition 2	Condition 1 v. Condition 3	Condition 2 v. Condition 3
Color Trails	1.00	0.74	0.76
Stroop	0.17	0.99	0.21
Digit Span Backwards	0.06	0.77	0.24
Color Trails Difference	0.61	0.98	0.49
Stroop Difference	0.14	0.98	0.20

Key: Condition 1 = Interactive Cybercycle, Condition 2 = Synchronized Physical and Mental Exercise, Condition 3 = Mental Exercise Only

Table 7. Tukey Post-Hoc Tests for Differences in Executive Function With Fit Participants

Executive Function Measurement	Condition 1 v. Condition 2 (*p* value)	Condition 1 v. Condition 3 (*p* value)	Condition 2 v. Condition 3 (*p* value)
Color Trails	0.95	1.00	0.96
Stroop	0.31	0.78	0.72
Digit Span Backwards	0.36	0.89	0.65
Color Trails Difference	0.89	0.76	0.97
Stroop Difference	0.31	0.50	0.94

Key: Condition 1 = Interactive Cybercycle, Condition 2 = Synchronized Physical and Mental Exercise, Condition 3 = Mental Exercise Only

Table 8. Comparing Neuropsychological Outcomes of Combined or Single Exercise

	Mean **Combined Physical And Mental Exercise Conditions**	**Mean** **Mental Exercise Only Condition**	**p values**
All Participants in Condition no Covariates	***n* = 20**	***n* = 10**	
Color Trails Difference Score	-0.49	5.40	0.27
Only Use Fit Participants	***n* = 16**	***n* = 7**	
Color Trails Difference Score	-2.9	9.6	0.04
Color Trails	-7.2	2.6	0.08

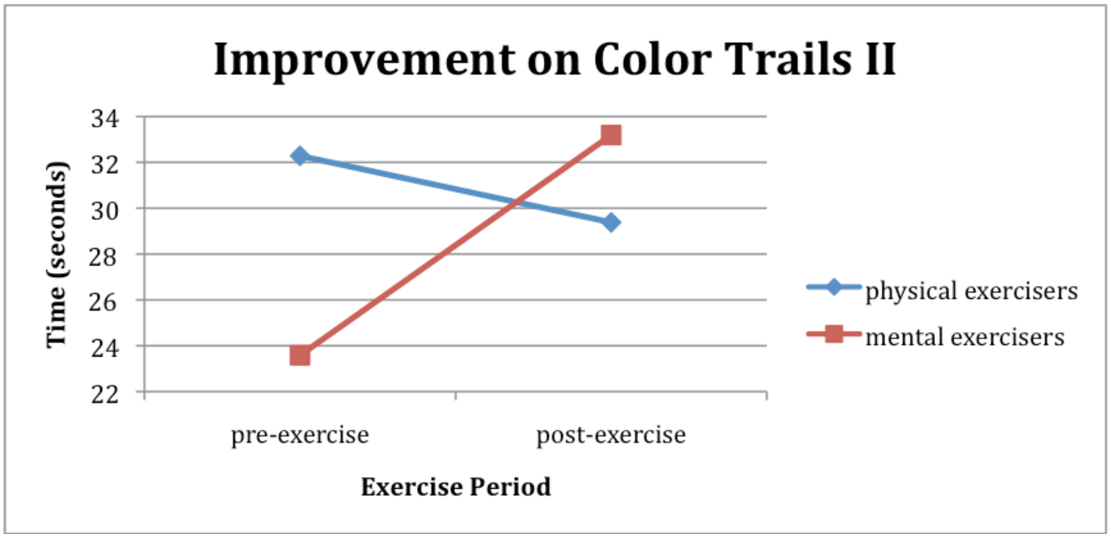

Figure 1. This graph shows the effects of combined physical and mental exercise compared with mental exercise only on executive function. This graph only took into account the fit participants' results (n=23). The scores that were used were the Color Trails Difference scores. The x-axis represents the time the participants completed the neuropsychological test. The pre-exercise period represents the participants' baseline performance; whereas the post-exercise period shows the effects exercise had on executive function. The y-axis represents the time in seconds it took the participants to complete the test. A lower time indicates better performance; thus better executive function. There was a non-significant difference in the pre-test scores between the two conditions; $p = 0.11$. The participants in the combined physical and mental exercise conditions had a significant improvement compared to the participants in the mental exercise only conditions, $F(1,21) = 4.98$, $p < 0.05$. The mental exercise only participants actually got slower from their pre-test evaluation to their post-test evaluation. This data suggests that a combination of physical and mental exercise increases executive function more than mental exercise alone.

APPENDIX A

Participant ID# ___________ Date ____________
Location: Psych Lab Bailey 203
Evaluator Initials __________ Time (include am or pm) ____________

Experimental Condition: _______________________

Instructions Form

______ Pre-Session Checklist:

- ______ Pen, Stopwatch (Or cell phone with timer on it)
- ______ Informed Consent Form
- ______ Demographic Questionnaire
- ______ Exercise History Questionnaire
- ______ Color Trails Version 1 & 2 Neuropsych Test
- ______ Stroop Neuropsych Test
- ______ Digit Span Neuropsych Test
- ______ Educational Television Questionnaire
- ______ Debriefing Statement
- ______ iPod (with gym backgroun noise), iPod Dock/Speakers.
- ______ Participant's compensation (course credit)
- ______ Set up cybercycle or stationary bike (the cybercycle in TV Mode)

______Welcome participant to the study.

______ Give participant a copy of the Informed Consent Form.

Please read this Informed Consent form carefully and sign at the bottom. If you have any questions, do not hesitate to ask.

______ Administer Demographic Questionnaire and Exercise History Questionnaire

Please fill out these questionnaires to the best of your ability. Remember that all answers will remain confidential.

_____ Administer Color Trails (time to complete if less than 60 sec or stop participant at 60 sec and record # correct)

Be sure to be ready with the stopwatch, even a one second difference in recording time can be significant..

PRACTICE:
In this box are different colored circles with numbers in them. When I say "begin," I want you to take this pen and connect the circles by going from 1 *(point to the 1),* **2** *(point to the 2),* **3** *(point to the 3)***, and so on, until you reach**

the end. I want you to connect the circles in the correct order as quickly as you can, without lifting the pen from the paper. If you make a mistake, I will point it out. When I do, I want you to move the pen back to the last correct circle and continue from there. The line that you draw must go through the circles and must do so in the correct order. Do you have any questions? Okay, let's practice. Put your pen here where this hand tells you to start. When I say "begin," connect the circles in order as quickly as you can until you reach the circle next to the hand telling you to stop. Ready? Begin. *(Begin timing as soon as you detect movement toward the first circle.)*

TEST:
Now I have a sheet with several more numbers and circles. Connect the circles in order like you did just a moment ago. Again, work as quickly as you can, and do not lift the pen from the paper as you go. Make sure that your lines touch the circles. *Point to the first circle and say the following:* **You will start here, where the hand tells you to start, and end where the hand tells you to stop. Ready? Begin.** *(Begin timing as soon as you detect movement toward the first circle. Be sure to record # of dot just completed at 60 seconds, as well as time to complete all).*

Record circle color and number at 60 seconds: _____

Record time to complete (in seconds): _____

PRACTICE:
In this box are different colored circles with numbers in them. This time I want you to take the pen and connect the circles in order by going from *this* color 1 *(point to the pink 1)*, **to *this* color 2** *(point to the yellow 2)*, **to *this* color 3** *(point to the pink 3)*, **and so on, until you reach the last number next to the hand telling you to stop.** *Take the pen and point to the example below the box as you say the following:* **Notice that the color changes each time you go to the next number. I want you to work as quickly as you can. Do not lift the pen from the paper once you have started. If you make a mistake, I will point it out. When I do, I want you to move the pen to the last correct circle and continue from there. As before, the line you draw must go through the circles in the correct order. Do you have any questions? Okay, let's practice. Put your pen here next to the hand telling you to start. When I say "begin," connect the circles in order as quickly as you can, changing from one color to the next, until you reach the hand telling you to stop, Ready? Begin.** *(Begin timing as soon as you detect movement toward the first circle.)*

TEST:
Now I have a sheet with several more numbers and colored circles. Connect the circles like you did just a moment ago. Again, work as quickly as you can. *Point to the first circle and say the following:* **You will start here, where the hand tells you to start, and end where the hand tells you to stop. Ready?**

Begin. *(Begin timing as soon as you detect movement toward the first circle. Be sure to record # of dot just completed at 60 seconds, as well as time to complete all).*

Record circle color and number at 60 seconds: _____

Record time to complete (in seconds): _____

_____ Administer the Stroop Task (PROSPER version – 40 items)

Before showing the examinee any of the cards, say:

COLOR BLOCKS:
You might find the next task interesting. I am going to show you a few different pages. On this first page, you will see there are some colored blocks. Please tell me the names of the colors you see on this top, sample row (point to the row)**.**

If necessary, clarify that the names to use are: red, blue & green. If the examinee cannot distinguish the colors, perhaps due to color-blindness, move on to the next task. If the examinee completes the sample line successfully, say:

Good. Now I want you to tell me the names of each color block starting here and going as quickly as you can, without making mistakes, across the row and down to the next line and across, etc., until you finish all the rows (point to the end)**. Are you ready? Go.** (Be sure to start & stop the timer precisely. Mark all answers on your record sheet so that you can tally the number of errors later. Examinee can self-correct, but do not prompt for corrections)**.**

BLACK WORDS:
Good, on the next page you will see that the task is similar, but slightly different. Here, read the words as quickly as you can. Please try the sample line (point)**.**

Fine. Now I want you to start here (point) **and read across as quickly as you can without making mistakes. Again, go across each row and then down until you finish all the rows** (point to the end)**. Are you ready? Go.**

COLORED WORDS (incongruous/interference):
Good. On this last page, your task is to tell me the color of the ink and ignore the written word. (Feel free to empathize if the examinee laughs, gasps, etc. – e.g., say something like: **I realize this is getting more challenging, but do the best you can). Please try the sample line.**

Fine. *(If not, please explain again and repeat practice until clear understands, or abandon task).* **Start here** (point) **and read across and then down as quickly as you can without making mistakes until the end** (point). **Are you ready? Go.**

_____ Administer Digit Span (digits forward)

Read numbers at rate of one second per number, with downward intonation at end. Be sure to record all responses whether right or wrong. Discontinue after 2 failures of the same length of digits.

I am going to say some numbers. Listen carefully, and when I am through, I want you to say them right after me. Just say what I say.

_____ Administer Digit Span (digits backward).

Read numbers at rate of one second per number, with downward intonation at end. Be sure to record all responses whether right or wrong. Discontinue after 2 failures of the same length of digits.

Now I am going to say some more numbers. But this time when I stop, I want you to say them backward. For example, if I say 7-1-9, what would you say?

______ CONDITION 1: CYBERCYCLE

INSTRUCTIONS FOR CYBERCYCLE: **Here is the cycbercycle that you will be using to exercise. Please sit on the bicycle and adjust the seating using the red bar in front of the seat so that you are comfortable. The bars on either side of you are what you will use to steer. To steer right, you will lift the left handlebar and push down the right. To steer left you will lift the right handlebar and push down the left. The red buttons on the handlebars change the gears of the bike, and the gear indicator is located in the bottom-right corner of the screen. For both handlebars, the right red button decreases the gear and the left red button increases the gear. Do you have any questions?**

______ Measure resting heart rate and instruct participant to begin warm-up.

Before we begin, please hold on to the handlebars so that we can get a reading of your resting hear rate. Now you will begin a cycling warm-up. We would like you to cycle at approximately 55 RPM for a total of 5 min. Here is where you can locate RPM on your screen (*point to RPM on the left side of the cybercycle screen*). Please let me know when you are ready to begin and I will start the stopwatch. I will let you know when the 5 min is up.

***Cybercycle Participants: Select "Express" course**

WHILE PARTICIPANTS ARE WARMING UP SHOW PARTICIPANTS WHERE HEART RATE IS LOCATED ON THE SCREEN. ALSO, USING THE KARVONEN FORMULA, MEASURE PARTICIPANT'S TARGET HEART RATE.

Target Heart Rate = [(220-age) – (Resting Heart Rate)] x 60% + Resting Heart Rate

During this exercise session, we want you to try to reach and maintain an exercise intensity equal to 60% of your heart rate reserve during a 20 min exercise bout. In order to achieve this, try your best to exercise at a pace so that your heart rate is around _________ beats per minute (bpm) (+ or - 10 bpm). To help reach and maintain your target heart rate, you may adjust the gears to change pedaling resistance. Remember that increasing the gear and resistance will help raise heart rate. The bottom right of the screen tells you which gear you are on.

Let me know when you are ready to begin. Once participant says they are ready:

- o Click play on the audio background tape
- o Select the Fruitdale course for them

Now you can begin exercising (Start stopwatch for 20mins)

______ EXERCISE CONDITION 2: STATIONARY BIKE & INDEPENDENT MENTAL EXERCISE

INSTRUCTIONS FOR STATIONARY BIKE: **Here is the stationary bike that you will be using to exercise. Please sit on the bicycle and adjust the seating using the red bar in front of the seat so that you are comfortable. The bars on either side of you are the handlebars. The red buttons on the handlebars change the gears of the bike, and the gear indicator is located in the bottom-right corner of the screen. For both handlebars, the right red button decreases the gear and the left red button increases the gear. Do you have any questions?**

______ Measure resting heart rate and instruct participant to begin warm-up.

Before we begin, please hold on to the handlebars so that we can get a reading of your resting hear rate. Now you will begin a cycling warm-up. We would like you to cycle at approximately 55 RPM for a total of 5 min. Here is where you can locate RPM on your screen (*point to RPM on the left side of the cybercycle screen*). Please let me know when you are ready to begin and I will start the stopwatch. I will let you know when the 5 min is up.

***Stationary Bike: Select "Express" course and immediately select TV mode.**

INSTRUCTIONS FOR SETTING UP THE TV PROGRAM:
You will be watching 20mins of an educational documentary on the planet Mars. There will be a 5-question quiz following this acute exercise bout on the program, so please try your best to pay attention to the program. I will start the program during your 5 minute warm-up and briefly pause it after the 5 minutes are up. I will resume the program when you begin your 15 minute acute exercise bout. Please try to pay attention the entire time.

WHILE PARTICIPANTS ARE WARMING UP SHOW PARTICIPANTS WHERE HEART RATE IS LOCATED ON THE SCREEN. ALSO, USING THE KARVONEN FORMULA, MEASURE PARTICIPANT'S TARGET HEART RATE.

Target Heart Rate = [(220-age) – (Resting Heart Rate)] x 60% + Resting Heart

Rate

During this exercise session, we want you to try to reach and maintain an exercise intensity equal to 60% of your heart rate reserve during a 20 min exercise bout. In order to achieve this, try your best to exercise at a pace so that your heart rate is around _________ beats per minute (bpm) (+ or - 10 bpm). To help reach and maintain your target heart rate, you may adjust the gears to change pedaling resistance. Remember that increasing the gear and resistance will help raise heart rate. The bottom right of the screen tells you which gear you are on.

Let me know when you are ready to begin. Once participant says they are ready:

- Click play on the audio background tape
- Make sure the TV show is set at the beginning & is titled "Mars: The Red Planet"
- Click play on the TV show
- Select fruitdale course then IMMEDIATELY TURN ON TV mode on the bike

Now you can begin exercising. (Start stopwatch for 20mins)

______ EXERCISE CONDITION 3: MENTAL EXERCISE ONLY

INSTRUCTIONS FOR SETTING UP THE TV PROGRAM:
You will be watching 20mins of an educational documentary on the planet Mars. There will be a 5-question quiz following this acute exercise bout on the program, so please try your best to pay attention to the program.

Let me know when you are ready to begin. Once participant says they are ready:

- Click play on the audio background tape
- Make sure the TV show is set at the beginning & is titled "Mars: The Red Planet"

Click play on the TV show (Start stopwatch for 20mins)

______ Offer participant a glass of water. Give participants the Post-Neuropsych Evaluation

If Condition 1: Administer Post-Exercise Questionnaire
Please complete this questionnaire to the best of your ability.

If Condition 2 or 3: Administer TV Quiz
Please complete this quiz to the best of your ability.

All Conditions:
You will now take the same neuropsych tests you completed earlier. After we are done with the evaluations, we will move on to the final part of the study. Do you have any questions?

_____ Administer Color Trails (time to complete if less than 60 sec or stop participant at 60 sec and record # correct)

Be sure to be ready with the stopwatch, even a one second difference in recording time can be significant..

PRACTICE:
In this box are different colored circles with numbers in them. When I say "begin," I want you to take this pen and connect the circles by going from 1 *(point to the 1),* **2** *(point to the 2),* **3** *(point to the 3)*, **and so on, until you reach the end. I want you to connect the circles in the correct order as quickly as you can, without lifting the pen from the paper. If you make a mistake, I will point it out. When I do, I want you to move the pen back to the last correct circle and continue from there. The line that you draw must go through the circles and must do so in the correct order. Do you have any questions? Okay, let's practice. Put your pen here where this hand tells you to start. When I say "begin," connect the circles in order as quickly as you can until you reach the circle next to the hand telling you to stop. Ready? Begin.** *(Begin timing as soon as you detect movement toward the first circle.)*

TEST:
Now I have a sheet with several more numbers and circles. Connect the circles in order like you did just a moment ago. Again, work as quickly as you can, and do not lift the pen from the paper as you go. Make sure that your lines touch the circles. *Point to the first circle and say the following:* **You will start here, where the hand tells you to start, and end where the hand tells you to stop. Ready? Begin.** *(Begin timing as soon as you detect movement*

toward the first circle. Be sure to record # of dot just completed at 60 seconds, as well as time to complete all).

Record circle color and number at 60 seconds: _____

Record time to complete (in seconds): _____

PRACTICE:
In this box are different colored circles with numbers in them. This time I want you to take the pen and connect the circles in order by going from *this* color 1 *(point to the pink 1)*, **to *this* color 2** *(point to the yellow 2)*, **to *this* color 3** *(point to the pink 3)*, **and so on, until you reach the last number next to the hand telling you to stop.** *Take the pen and point to the example below the box as you say the following:* **Notice that the color changes each time you go to the next number. I want you to work as quickly as youcan. Do not lift the pen from the paper once you have started. If you make a mistake, I will point it out. When I do, I want you to move the pen to the last correct circle and continue from there. As before, the line you draw must go through the circles in the correct order. Do you have any questions? Okay, let's practice. Put your pen here next to the hand telling you to start. When I say "begin," connect the circles in order as quickly as you can, changing from one color to the next, until you reach the hand telling you to stop, Ready? Begin.** *(Begin timing as soon as you detect movement toward the first circle.)*

TEST:
Now I have a sheet with several more numbers and colored circles. Connect the circles like you did just a moment ago. Again, work as quickly as you can. *Point to the first circle and say the following:* **You will start here, where the hand tells you to start, and end where the hand tells you to stop. Ready? Begin.** *(Begin timing as soon as you detect movement toward the first circle. Be sure to record # of dot just completed at 60 seconds, as well as time to complete all).*

Record circle color and number at 60 seconds: _____

Record time to complete (in seconds): _____

_____ Administer the Stroop Task (PROSPER version – 40 items)

Before showing the examinee any of the cards, say:

COLOR BLOCKS:
You might find the next task interesting. I am going to show you a few different pages. On this first page, you will see there are some colored

blocks. Please tell me the names of the colors you see on this top, sample row (point to the row)**.**

If necessary, clarify that the names to use are: red, blue & green. If the examinee cannot distinguish the colors, perhaps due to color-blindness, move on to the next task. If the examinee completes the sample line successfully, say:

Good. Now I want you to tell me the names of each color block starting here and going as quickly as you can, without making mistakes, across the row and down to the next line and across, etc., until you finish all the rows (point to the end)**. Are you ready? Go.** (Be sure to start & stop the timer precisely. Mark all answers on your record sheet so that you can tally the number of errors later. Examinee can self-correct, but do not prompt for corrections)**.**

BLACK WORDS:
Good, on the next page you will see that the task is similar, but slightly different. Here, read the words as quickly as you can. Please try the sample line (point)**.**

Fine. Now I want you to start here (point) **and read across as quickly as you can without making mistakes. Again, go across each row and then down until you finish all the rows** (point to the end)**. Are you ready? Go.**

COLORED WORDS (incongruous/interference):
Good. On this last page, your task is to tell me the color of the ink and ignore the written word. (Feel free to empathize if the examinee laughs, gasps, etc. – e.g., say something like: **I realize this is getting more challenging, but do the best you can). Please try the sample line.**

Fine. *(If not, please explain again and repeat practice until clear understands, or abandon task).* **Start here** (point) **and read across and then down as quickly as you can without making mistakes until the end** (point)**. Are you ready? Go.**

_____ Administer Digit Span (digits forward)

Read numbers at rate of one second per number, with downward intonation at end. Be sure to record all responses whether right or wrong. Discontinue after 2 failures of the same length of digits.

I am going to say some numbers. Listen carefully, and when I am through, I want you to say them right after me. Just say what I say.

_____ Administer Digit Span (digits backward).

Read numbers at rate of one second per number, with downward intonation at end. Be sure to record all responses whether right or wrong. Discontinue after 2 failures of the same length of digits.

Now I am going to say some more numbers. But this time when I stop, I want you to say them backward. For example, if I say 7-1-9, what would you say?

______ Debrief and compensate participant.

Give the participant the debriefing form and tell them to read through it. At the end please thank them for their participation.

Appendix B

Independent Mental & Physical Exercise Condition:
Educational Television Show Questionnaire
The Universe: Season 1, Ep 2-Mars: The Red Planet

Participant ID#_____________

1) What place in the US is similar to Mars?

2)What is the tallest peak in the solar system?

3) Since there is no Oxygen on Mars, what is the air made of?

4) Has any trace of water been detected on Mars?

5) Have we ever launched spacecrafts to Mars?

Appendix C

Cybercycle Condition:
Post-Exercise Questionnaire

Participant ID#_____________

1) What were some of the things you noticed in the virtual track?

2) Did you find yourself competing against the virtual riders?

3) Did you feel you exercised at similar intensity to how you would exercise on a bike at your normal gym?

4) Did you find this kind of interactive exercise more enjoyable than a standard bike would be?

5) What are some things that would have made this exercise session more enjoyable?

Appendix D

Exercise History Questionnaire

Participant ID# ____________________

Which one of the five physical activity categories reflects your usual pattern of daily physical activity? Please check the box next to each level of physical activity.

- ☐ **Level 1**: Inactive or little activity other than usual daily activities.
- ☐ **Level 2**: Regular (>5 days/week) participation in physical activities for at least 10 min at a time that require low levels of exertion resulting in only slight increases in breathing and heart rate.
- ☐ **Level 3**: Engage in aerobic exercises (e.g. brisk walking, joggning or running, cycling, swimming, or vigorous sports) at a comfortable pace for 20-60 min per week.
- ☐ **Level 4**: Participate in aerobic exercises at a comfortable place for 1-3 hour per week.
- ☐ **Level 5**: Participate in aerobic exercises at a comfortable pace for over 3 hours per week.

Please answer the following questions to the best of your ability.

1) Approximate length (min) of a single session of exercise ________________

2) Identify which type(s) of exercise of which you typically participate.

- ☐ Strength/Resistance Exercise (e.g. weightlifting)
- ☐ Flexibility Training/Exercise (e.g. static or dynamic stretching)
- ☐ Stamina and Endurance Exercise (e.g. cardiovascular exercise, all types of aerobic exercise)
- ☐ Balance Exercise (e.g. Yoga)

3) Rate the intensity at which you typically exercise:

Low Intensity   Moderate/Self-Paced Intensity   High Intensity

4) What is your reason for exercising? (please circle all that apply)

To loose weight   To stay healthy   Because it is enjoyable   Other

If other, please specify:____

Appendix E

Demographic Questionnaire

Participant ID#______________

Date ____
DOB ____
Class Year ____
Major/Minor ____
Gender ____
Handedness ____
Height (ft/in) ____
Weight (lbs.) ____

(*Note: Remember that all information will remain confidential. Please write your height and weight as accurately as possible or to the best of your knowledge.*)

Ethnicity/Race (two-part question):

Are you Hispanic or Latino? Yes No

Please select one or more races that you identify with:

- ☐ American Indian or Alaskan Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White
- ☐ Other (*please specify*): ____

<u>Medical and Developmental History</u>:

Any History of…

Loss of consciousness YES / NO
(car accident, sport injury, drinking…)
when ____
how long out ____
what treatment (ER, scans…) ____

Seizures YES / NO
when ____
type/frequency ____
what treatment ____

Stroke/Brain infections YES / NO
when ____
how many/effects ____
what treatment ____

Toxic exposures YES / NO
(e.g., chemical exposure - factory work, landscaping)
when ____
how many/effects ____
what treatment ____

Medical History:

Major medical problems treated for now:

____
____
____
____

Substances Taken in the last 12 Hours (check all that apply):

Substance	Used in Past 12 hrs (please put an X if Yes)
Caffeine	
ADHD Stimulant Medication	
Alcohol	
Other (please specify)	

Did you participate in any varsity athletic team(s) in high school? Yes No
If yes, please specify:____

Have you participated in any varsity athletic team(s) in college? Yes No
If yes, please specify:____