The Effects of Running Durations on Executive Function

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The Effects of Running Durations on Executive Function

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Dedication

This thesis is dedicated to the late Bennett Dean Felix Carriere ("Uncle Benny") whose academic footsteps I have followed through my research. His eccentric spirit has guided me through this process and will always continue to do so throughout all of my future endeavors.

Acknowledgements

There were many people that supported my aspirations and made this thesis possible. I would have not been able to complete this thesis without the guidance of my amazing committee, Dr. Greggory Davis, Dr. Michael McDermott, and Dr. Jeremy Foreman. The honors department, especially Dr. Julia Frederick, also guided me along this process. I am truly grateful for their extensive knowledge and generosity that has led me through my academic journey.

My family, especially my loving parents, and supporting faculty have always encouraged me to never stop trying to achieve my fullest potential. All of the dedication to this thesis has been worth the sacrifices in order to advance my knowledge as well as contribute to the field of exercise science.

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Abstract

The purpose of this study was to examine the relationship between running habits and specific executive functions. Three cognitive function tests were administered virtually to men and women ages 18 – 61 through a validated web-based application (PsyToolKit) and were preceded by a demographic questionnaire. A total of 199 participants were analyzed. The cognitive functions assessed were cognitive inhibition by the Stroop Color and Word Test, visuospatial short-term working memory by the Corsi block-tapping test, and working memory capacity by the 2-back task. A linear regression was used to determine relationships between running and cognitive function. Significant correlations were found for all three tests. Stroop Color and Word Test correct matches positively correlated with running days (r = 0.123, p = 0.042). Corsi block-tapping test highest score negatively correlated with running miles (r = -0.155, p = 0.033). 2-back task median reaction time negatively correlated with running days (r = -0.147, p = 0.041). 2-back task mean reaction time negatively correlated with running miles (r = -0.0158, p = 0.028) and running days (r = -0.162, p = 0.024). 2-back task missed questions negatively correlated with running miles (r = -0.167, p = 0.02) and running days (r = -0.151, p=0.036). 2-back task correct matches positively correlated with running miles (r = 0.171, p = 0.017). While these correlations do not imply causation, results indicate a general improvement of cognitive test scores as individuals increase running volume. Study results suggest that running on a regular basis may be beneficial for improvement of executive functions, especially cognitive inhibition and working memory capacity. The data also suggest a possible dose-response relationship.

Introduction

Running has a number of positive effects on cognitive function. Specifically, changes in executive functioning occur after this strenuous exercise. Executive functioning is defined as "the ability to hold in mind information in working memory, to inhibit fast and unthinking response to stimulation, and to flexibly shift the focus of one's mental frame" (Blair, 2016). Research to identify if runners have better executive functioning than individuals who do not run is important to understanding the neurological benefits of running. If an individual is fit to endure running, it can be proposed as a method for enhancing brain function to individuals that seek non-pharmacological solutions. Research has been done to determine how this functioning is affected before and after races of runners. But substantially less research has been conducted to assess the differences in executive function among runners and those who do not run within their daily lives (i.e., not immediately before or after races).

In order to determine the extent to which executive functioning may differ among runners, a sample of runners who are actively training as well as a sample of control individuals who do not run will be analyzed. The executive functions will be separated by categories in order to determine if these aspects of executive functioning significantly differ in runners as compared to non-runners. The three main executive functions tested in this study are cognitive inhibition, visuospatial short-term working memory, and working memory capacity which will be assessed by three psychological tests. The tests administered in this study are the Stroop Color and Word Test, the Corsi block-tapping test, and the 2-back task, which provide quantitative scores to analyze the three categories, respectively. The categories will also be analyzed separately to determine the extent to which the categories are impacted that result in better overall cognitive function. It is hypothesized that runners have a better overall score in tests that assess cognitive functioning, especially executive functioning, as compared to individuals who do not regularly run.

This study will contribute data for the determination of whether runners have better executive functioning cognition skills than the population who does not engage in this type of physical activity. The differences in executive functioning scores of runners and those who do not run as well as the differences of scores in particular executive functioning categories will be assessed. If there are significant results in the variation of scores, more support will be provided to encourage running to be included as part of treatment plans for individuals in need of cognition skill improvements.

The purpose of this study is to determine if there are executive functioning differences in runners compared to individuals who do not run. Further, the study is aimed to determine what, if any, specific categories of executive functioning have the best scores in the runner population. The predicted outcome is that runners will have better executive functioning, but which category runners will have the best score in is unknown. Cognitive outcomes of exercise, especially aerobic exercise, is widely studied. Contributing more data about the specific relationships between exercise and different forms of executive functions can help professionals propose non-drug treatments for cognitive improvements in the form of running. In addition, those who are physically fit, can know the benefits of why maintaining a physically active lifestyle is important beyond bodily, or physiological, benefits.

Literature Review

Cognitive Function

"Cognitive function is a broad term that refers to mental processes involved in the acquisition of knowledge, manipulation of information, and reasoning. Cognitive functions include the domains of perception, memory, learning, attention, decision making, and language abilities" (Kiely, 2014). It plays a vital part in every individual's daily life. In general, the maintenance of cognitive functioning provides a variety of benefits to healthy individuals as well as to individuals who are diagnosed with physical and psychological / intellectual disorders. Ensuring that one's cognitive functioning is stimulated and enhanced has shown to be a critical component in many factors of wellbeing. A main focus of attention is the correlation of healthy cognitive functioning with delayed mortality (Smits, 1999), especially in older adults. As a whole, cognitive functioning provides a benchmark for measuring many aspects of health that pertain to not only individual prosperity but also to the successful functioning and wellness of society.

The focus of this study, executive functioning, refers to a component of cognitive functioning that is a set of mental skills which are "necessary for carrying out higher order cognitive processes" (Lagattuta, 2015). These include and are not limited to inhibition, working memory, and attention. Cognitive inhibition is relevant to the Stroop Color and Word Test used in this study. It "refers to the ability to effectively inhibit the processing of previously relevant or irrelevant information" (Koster, 2011). Working memory is important to the Corsi block-tapping test and the 2-back task, which test visuospatial working memory and short-term working memory capacity, respectively.

Although working memory can have a wide variety of definitions, it is generally referred to as being "involved in goal-directed behaviors in which information must be retained and manipulated to ensure successful task execution" (Chai, 2018).

Physical activity/Exercise/Running Influences Cognitive Functioning

While the effects of physical activity and / or exercise on many neurological and physiological functions in human and animal studies is an extensive topic of research, this study expands on three specific executive functions, including cognitive inhibition, visuospatial working memory, and short-term working memory capacity, as a result of participating in running.

Physical Activity

To begin with, it is important to note the differences between physical activity and physical exercise. According to the World Health Organization (2010), physical activity is "any bodily movement produced by skeletal muscles that require energy expenditure." On the other hand, physical exercise is "a sub classification of PA [physical activity] that is planned, structured, repetitive, and has as a final or an intermediate objective the improvement or maintenance of one or more components of physical fitness" (World Health Organization, 2010). This section will focus on the general benefits of physical activity on cognitive functioning. This is a very extensive and wide range of research. The most prominent findings and areas of research will be presented.

Ihara et. al (2013) used physical activity as an intervention for patients (n = 10) with vascular cognitive impairment by instructing them to take walks with varying distances and step counts. The average step number and walking distance significantly correlated with the total scores and sub scores of visuospatial / executive performance of the Japan version of the Montreal Cognitive Assessment (MoCA-J). Notably, this was the only sub score to correlate with those physical activities. The correlation was positive for the total scores of the MoCA-J (walking: $r = 0.64$, step number: $r = 0.67$) and the visuospatial / executive performance sub scores (walking: $r = 0.658$, step number: $r = 0.664$). The following scores were included but did not correlate. Total scores and all sub scores of the Mini-Mental State Examination (MMSE) did not correlate. Sub scores of the MoCA-J, including naming, memory, attention, language, abstraction, and orientation, did not correlate. This study concluded it is very probable that physical exercise boosts executive functions, specifically in patients with “vascular cognitive impairment of subcortical origin” (Ihara, 2013). The focus on executive functions, especially visuospatial performance, directly relates to the current study because visuospatial working memory is one of the three executive functions tested. Because the visuospatial / executive performance sub score was the only sub score to significantly correlate with physical activity, it can be inferred that these processes are positively affected by physical activity and will also be positively correlated in the study. Further, this significant improvement in executive function and visuospatial performance has been correlated with improved brain health, such as neurogenesis and the secretion of protective factors, which is very important to individuals with neurological conditions. These neurological changes are presented several times throughout this review.

Another study focusing on intervention was conducted by Ploughman (2008) on disabled youth. There was a review of many different disabilities, such as cerebral palsy and dyslexia, and a variety of different interventions, such as home and communal physical activity programs. It supports the brain-derived neurotropic factor (BDNF) and neurogenesis role presented later in this review by Ferris (2007) and Praag (1999), respectively. It was found that exercise increases neurotrophins, especially BDNF, insulin-like growth factor-1 (IGF-1), and basic fibroblast growth factor (bFGF). Specifically, BDNF plays a key role in memory retention in the hippocampus as well as enhancing synaptic signaling. Neurtrophin proteins also support brain plasticity, which can be especially important for disabled youth. Physical activity also induced neurogenesis that repaired injured brain regions in mice studies (Hicks, 2007). Thereby, this repair mechanism may be able to assist youth with cognitive impairments.

Donnelly et. al (2016) conducted an extensive review of 137 current studies (1990-2014) to assess the effects of physical activity on brain structure, brain function, cognition, learning, academic achievement, and attention in children aged 5-13 years. Cross-sectional studies' findings were consistent with the result of physically fit children producing better cognitive test scores. Further, short-term bouts of physical activity were suggested to be the most prominent intervention that enhanced cognitive functioning among this age group. The structure and function of the brain was also improved in children participating in physical activity. This in turn boosts cognitive functioning. Notably, there is a very limited area of research on the neurological changes in children due to physical activity. Due to the positive correlation between physical activity and cognitive function in children, it is believed the improved cognitive functioning would carry over into a classroom setting and result in higher academic achievement. Findings were inconsistent, but cross-sectional and longitudinal studies produced favorable outcomes. The inconsistency is partly due to the many external factors that affect children's academic performance, such as the home environment, as well as the use of many different standardized tests to assess academic achievement. This testing issue is mainly due to the specificity or broadness of the processes assessed. The most prominent result that studies agree on though is the increase in processing speed and rapid decision making as a result of increased physical activity. Conclusions were also limited based on the wide variety of physical activity intervention used. As a whole, physical activity produced positive results in a variety of cognitive and academic processes in children. The research on this topic has many contradictions and structural factors to solve. But it is believed that physical activity has either an overall positive influence or an inconclusive one and does not have a declining effect.

Physical activity can also play an important protection role in aging adults. A study by Loprinzi (2016) about the degree to which physical activity regulates the correlation between cognitive functioning and multimorbidity investigated this relationship. Multimorbidity is defined as the co-occurrence of two or more chronic diseases, which were diagnosed by a physician in this study, and included arthritis, coronary artery disease, stroke, congestive heart failure, heart attack, emphysema, chronic bronchitis, hypertension, diabetes, cancer, and obesity. Data from the National Health and Nutrition Examination Study (NHANES) of adults aged 60-85 years (n = 2,157) was analyzed. The intervention of physical activity this age group underwent consisted of five intensity categories based on metabolic equivalent for task (MET) level. Notably, the participants reported performing leisure-time physical activity before the intervention that included 16 sport-related, 14-exercise related, and 18 recreational-related activities. The digital symbol substitution test (DSST) was used to assess cognitive functioning and included an executive functioning of the frontal lobe component. This is especially significant to the current study as it focuses on the specific domain of cognitive functions, executive functioning. The result that multimorbidity inversely correlated with cognitive function supported the notion that this is a regular phenomenon in almost all studies. Further, when the minimum amount of physical activity, 2000 MET-min-month (MET level*duration*days), was performed by participants, there was no correlation between multimorbidity and cognitive function. Overall, physical activity served as a protection and preserving factor against the reduction of cognitive function that is due to multimorbidity. Those who participated in greater amounts of physical activity did not have the correlation of multimorbidity associated with lower cognitive function.

A study by Voss et. al (2013) explored the specific neurological changes caused by physical activity in aging adults, 55 to 85 years old (n = 70). The integrity of cerebral white matter was assessed in this age group of a sedentary population because it is a major factor in neurological and cognitive function decline in elderly adults. The two physical activity groups involved consisted of weekly aerobic intervention, a forty-minute walking session, and anaerobic intervention, a forty-minute stretching and toning session. After one year of this intervention, cognitive functioning scores with an executive function component were compared. These included the forward and backward digit span tasks to measure short-term memory, a spatial working memory task, a task-switching test to measure the flexibility and reaction time when switching attention, and the Wisconsin card sorting task to measure working memory, inhibition, and switching capacity. It was found that increased aerobic activity was associated with the greatest positive change in cerebral white matter of the frontal and temporal lobes as well as in short-term memory. Notably, short-term memory improvement without the co-occurrence of physical activity did not improve cerebral white matter. Further, aerobic activity significantly increased the diffusivity of water across different regions of white matter in the prefrontal ($p = 0.001$), parietal ($p = 0.005$), and temporal ($p = 0.03$) lobes. This diffusivity is import to neural function because it is a measure of the amount of axons and their myelination. This was also a defining factor in this research as it demonstrates a more detailed result of the substrates that could cause cognitive decline due to a reduction in cerebral white matter. Overall, this study supports the notion that not only will executive function increase due to physical activity, especially aerobic activity which applies to the current study, but also that there are specific changes to the brain's physiology that induces these cognitive improvements.

Overall, physical activity influences many neurological factors that influence cognitive functioning. By incorporating physical activity in human and animals' lifestyles, there is an increase in the release of certain brain molecules and an enhancement of brain health. Thereby, physical activity plays a vital role in the improvement of cognitive functioning.

Physical Exercise

Physical exercise, defined above, focuses on specific aspects of physical activity that enhance cognitive functioning. Examples of physical exercise include and are not limited to aerobic exercise, such as running, and resistance training, such as weightlifting.

An important factor used in testing the effects of exercise on cognitive functioning is the levels of Serum Brain-Derived Neurotropic Factor (BDNF), which is found mostly in the hippocampal region and also in the anterior cingulate of the brain. Thus, it plays a significant role in memory. A study by Ferris et. al (2007) measured these effects using the Stroop Color and Word Test as well as blood samples that determined the amount of BDNF in the participants' systems. These assessments were taken before and after varying intensities of exercise on stationary cycles. The graded test consisted of participants cycling until they were fatigued while certain physiological measurements were taken. There was a thirty percent increase in BDNF levels after this test and significantly higher scores on the Stroop Color and Word Test. The endurance ride with ten percent added to the ventilation threshold of participants yielded a thirteen percent increase in BDNF levels as well as significantly higher scores in the Stroop Color and Word Test.

The endurance ride that subtracted twenty percent from the ventilation threshold did not increase BDNF levels. It can be concluded that the increase in BDNF levels was a result of the intensity at which the exercise was performed. Overall, acute and chronic exercise lead to an increase in BDNF levels in certain brain regions. Notably, further research with a larger sample size is needed to conclude if the increase in BDNF levels directly effects the increase in Stroop Color and Word Test scores.

In order to assess the further domains of physical exercise, Basso and Suzuki (2016/2017) focused on the cognitive effects of a single bout of acute exercise. Specifically, the neurophysical and neurochemical alterations were reviewed from human and rodent studies in order to address cognitive and behavioral changes as a result of this type of physical exercise. The three most impacted cognitive and behavioral aspects that remain consistent are executive functions, enhanced mood states, and decreased stress levels. The most prominent change in neurophysiology was the alternation of neurochemical levels, including neurotransmitters, metabolites, growth factors, and neuromodulators. The finding of this study relating to an increase in growth factors expands on the BDNF research (Ferris, 2007). Together, they further support the notion that physical exercise increases certain molecules in the brain which can have a positive benefit on certain cognitive functions.

A mice study by Feter et. al (2019) compared the differences between varying exercise types and levels as well as including sedentary mice. This was conducted in order to determine the chronic effects of physical exercise on cognitive functioning, including recognition and spatial memory. The physical exercise group of mice were put on a running wheel. The other exercise types included resistance training, high-intensity interval, and moderate-intensity continuous training. The spatial memory improvements were induced by exercise. This improvement was concluded to be a result of most likely stimulating IGF-1 which could act as an antioxidant protector factor and as a neurotrophic factor. Overall, by stimulating IGF-1 with physical exercise, in this case running, spatial memory will likely be improved.

Running

A prominent area of research for animal studies is the positive effect running has on spatial learning, long-term potential, and neurogenesis. In a study by Praag et. al (1999), the experimental group of mice were housed with a running wheel and deemed the runner group. The control group of mice were not housed with a running wheel. The ability of mice to learn and navigate the Morris water maze, which was configured in different ways (i.e., spatial learning) was increased in the runner group. Also, the runner group had strengthened neuron synapses which resulted in increased signal transmission (i.e., long-term potential) in the hippocampus. Neural cell division and replacement (i.e., neurogenesis) was also heightened with regular running in these mice. It has been found that one of the specific structures that correlates with these improvements is the dentate gyrus of the hippocampus. Thus, it could be implied that routine running improves brain health as well as the learning of spatial information due to its physiological effects in the brain, especially in the hippocampus, which plays a major role in memory.

Metcalfe and Teal (2006) conducted a study on a notable type of memory that is not focused on in the current study. Implicit and explicit memory was tested in marathon runners immediately after they completed a marathon race at the event site with a focus on neurohormonal changes and neuromodulators. “Explicit memory is information consciously recollected by the patient, and implicit memory is information that is not associated with any conscious recollection” (Lee, 2007). Scores from implicit and explicit memory tests were compared between marathon runners that completed the tests one week before the marathon race and runners who completed the tests immediately (within one week) after the marathon race. Results showed that the proportion of correctly recalled words on the explicit memory test was lower for the participants who took the test immediately after running a marathon. Further, the implicit memory test had better recall from the group of marathon runners who recently finished the race. This is hypothesized to be partly due to higher cortisol levels in marathon runners who have just finished a race. Other hormonal and physiological changes have been found to not have as a severe of an impact on memory to date according to this study’s research. An important factor to note is the effect of stress. The impairment of explicit memory may be due to exercise induced stress to bodily functions (Metcalfe & Teal, 2006). This was evident in a study by Graf and Schacter (1985) on amnesic patients. The effects on explicit memory for amnesic patients were similar to the effects shown by the marathon runners who recently finished a marathon race. The same word tests were used in both studies. There was a larger priming effect on the same-context words only when a study of the word pairs was completed, thus suggesting “word completion performance is mediated by implicit memory for new associations that is independent of explicit recollection” (Graf & Schacter, 1985). In summary, marathon running may have an effect on increasing implicit memory, while having a temporary effect on explicit memory decrease due to the body’s stress response.

Stroop Color and Word Test

The Stroop Color and Word Test has been and still continues to be a widely used psychological assessment implemented in a large variety of populations. It was developed by John R. Stroop in 1935 (Stroop, 1935) and continues to be a reliable measure of cognitive inhibition. Specifically, it is “used to assess the ability to inhibit cognitive interference that occurs when the processing of a specific stimulus feature impedes the simultaneous processing of a second stimulus attribute, well-known as the Stroop Effect” (Scarpina & Tagini, 2017). The Stroop Effect, which is the challenge of this task, is due to participants using a less autonomous response while inhibiting the interference of the automatic response. It has also been less commonly used to measure a number of other cognitive functions, and its reliability in measuring these still requires more research. These include the nonexecutive functions of attention and processing speed well as the executive functions of cognitive flexibility (Jensen & Rohwer, 1966) and working memory (Kane & Engle, 2003). The Stroop Color and Word Test has no restrictions or limitations on the populations it can be used on. It is used to compare scores of healthy adults and children, especially to measure the effects of exercise (assessed before and after exercise of experiment and control groups). It is also used in studies with populations that have mental and / or physical disorders, such as attention deficit hyperactive disorder (Langleben, 2006 & Homack and Riccio, 2004) and dementia (Koss, 1984), in order to help identify and / or assess severity. Overall, the task consists of the presentation of color words in varying ink colors. Participants must answer with the color of the ink rather than the name of the color word (i.e., answer yellow for the word *blue* presented in yellow ink). The score produced will be used to compare cognitive inhibition ability. The present study used a modified online edition of the Stroop Color and Word Test which requires button presses instead of verbal naming of the answers.

Corsi Block-Tapping Task

The Corsi block-tapping test was developed by Philip M. Corsi (Corsi, 1972) and is a psychological assessment of commonly visuospatial working memory as well as spatial attention. The current study measures visuospatial working memory with the forward Corsi task. The test begins with a two-block sequence that increases by one block each time the participants tap out the correct sequence. If an incorrect sequence is tapped out twice, the test concludes. The score produced, the Corsi block span, is the number of blocks the participants were able to correctly tap out in the presented sequence. A modified online version of this test was used in the present study. The online test used a sequence of square blocks which were presented in a different color from the rest one at a time in a pattern that had to be replicated in a forward sequence by the participants by taping their screens or mouse-clicking. It differs from the eCorsi test, which was used in the Brunetti (2014) study, that was purely touch-screen because participants could click the blocks with a mouse if a touch-screen device was unavailable to them. Using an online version of this test is actually more beneficial due to a more accurate score, more consistency with tapping blocks, and more control of inter-stimulus presentation timing (Brunetti, 2014). The Corsi block-tapping test has been used in healthy populations (Kessels, 2000) and in populations that have psychological and physical disorders. Disorders include and are not limited to Alzheimer's disease (Guariglia, 2007), brain damage and lesions (Kessels, 2000), and attention deficit hyperactivity disorder (Klingberg, 2002). It has been used across all age groups, including children (Pagulayan, 2006), adults, and elderly participants (Brunetti, 2014). This task has also been used to aid in the diagnosis of neuropsychological diseases (Brunetti, 2014).

2-back task

The n-back task (2 back) was developed by Wayne Kirchner (Kirchner, 1958) and is a measurement of short-term working memory capacity. This task provides a score of how well participants store information and notably not the skill of manipulating this information (Gajewski, 2018). The online implementation of this task comprised of a series of letters that were presented one at a time on the screens of the participants' devices. The participants decided if the current letter they are viewing was presented two stimuli (letters) ago. If it was, they pressed a specified key. If it was not, they waited until the next letter was presented. This task is mostly used in aging research (Gajewski, 2018) but has been used across all age groups, including children (Pelegrina, 2015). It has also been used in populations with neurological disorders, such as Parkinson's Disease (Miller, 2009), and mild cognitive impairment patients, such as Alzheimer's disease (Yener, 2013).

Methods

Participants

Ninety-three runners and one hundred six controls were administered an identical set of three psychological tests. Participant characteristics are available in Table 1. These runners as well as controls were recruited to participate in this study by e-mail or oral communication. Any person over the age of eighteen who was able to read and use an electronic device was allowed to participate. To qualify as a runner, participants were required to run at least once a week. The controls included any individual eighteen years of age or older who was capable of reading and completing an online survey and did not meet the qualifications to be considered an active runner.

Materials

Before the collection of data began, the Institutional Review Board of the University of Louisiana at Lafayette reviewed and approved all procedures and materials for this study. In order to begin the assessment, all participants had to sign a consent form. Once this form was electronically signed, the initial questionnaire and the psychological tasks became available. An online psychology testing website, PsyToolKit.org (Stoet, 2010, 2017), was used to administer a survey followed by three executive functioning tasks. The initial survey collected information about the participants' genders, ages, ethnicities, and running histories. The running history questions asked the following: days per week participants ran, miles per week the participants ran, number of marathon miles (26.2 miles) completed, number of half marathon miles (13.1 miles) completed, average finish time for marathon races, average finish time for half marathon races.

The executive functions tested were inhibition of cognitive interference assessed by the Stroop Color and Word Test, visuospatial short-term working memory assessed by the Corsi block-tapping test and working memory capacity assessed by the 2-back task. Two attention check questions were asked after the first and second tasks. These questions did not influence the data analysis. The questions were to determine if the participants were actively completing the tasks rather than aimlessly clicking through the survey and tasks. If a participant answered these questions incorrectly, the data from that participant was not analyzed. The questions proposed were common knowledge questions, such as “what color is the sky.” The question then prompted participants to select a specific, inaccurate response, such as “purple.”

Procedures

All participants were sent a link that directed them to a survey with embedded tests located on the website PsyToolKit. The online version of the Stroop Color and Word Test used in this study consisted of forty trials that lasted about two minutes. Forty color words were presented in a random order from a choice of the colors red, green, blue, and yellow. The purpose of this test was to press the key which represented the color of the text rather than the name of the color word (i.e., press the key that answered yellow for the word *green* presented in yellow font color), as demonstrated in Figure 1. Average response time was the quantitative factor measured in this test as well as the ability to inhibit cognitive interference.

The online implementation of the Corsi block-tapping test was developed from the original test which was not originally on online test. The test begins by displaying a pattern of blocks on the participant's screen that light up in a random sequence, as shown in Figure 2. After the word *go* is heard over the device's speaker, the participant must click the blocks in the sequence that was displayed. The test starts with a two-block sequence that progressively continues by one block if the sequence is clicked correctly. If the sequence is clicked incorrectly, the participant gets one more try. If this try was answered incorrectly, the test ends, and the working memory score is given.

The last task, the 2-back task, consisted of three blocks, which included a practice session to teach the participant how the test worked and two blocks that produced scores for data analysis. There were fifteen total stimuli using the letters A, B, C, D, E, H, I, K, L, M, O, P, R, S, and T. These letters were presented in a random order every 2760 milliseconds, which is shown in Figure 3. The participants had to press the "M" key on their keyboards if the letter presented was presented two letters ago. Each time a key was pressed, data regarding whether the selection was correct or incorrect were generated. Similarly, when no key was pressed when the letter matched the letter from two letters ago, a "miss" was recorded in the data. Each letter was displayed on the screen for a maximum of 760 milliseconds. Additionally, the intertrial interval was 200 milliseconds. The raw scores from these three psychological tests were then analyzed by a Pearson Correlation. The strength of correlation coefficients for the Pearson Correlation analysis are based on Akoglu (2018).

The three psychological tasks have been implemented in various studies testing the executive functioning of participants in relation to bouts of exercise. In a study measuring the correlation between executive functioning and lactate levels, which indicated intense exercise, the Stroop Color and Word Test was used as a reliable measure of some executive functions. This study found that there was a positive correlation between Stroop Color and Word Test scores and blood lactate levels. Thus, the intensity of exercise had an effect on the increase of the Stroop Color and Word Test scores (Coco, 2020). The Corsi block-tapping test was used to assess visuospatial memory as a result of low-impact aerobic running over a long-term period of time (a condition of the study), which was greater than eight months in this trial. Overall, the Corsi block-tapping test scores were higher when visuospatial memory was measured over eight months after this aerobic running was performed in comparison to the measurement taken immediately after performance. Notably, there were no non-runners in this study to compare scores of runners and non-runners (Winter, 2007). The last task in discussion, the 2-back task, was used in a study to measure working memory. The results of the study were that the 2-back reaction times were reduced in the active running population compared to the control population (Hogan, 2013).

Table 1: Characteristics of Participants

Characteristics	**Unit**				
Gender	Male/Female	82 Males	117 Females		
Age	Years (mean ± SD)		21 ± 5.3 years		
		Running Classifications			
Days per week ran	% of participants	None 53%	Low 20.7%	Moderate 19.2%	High 7.1%
Miles per week ran	% of participants	No Miles 53.3%	Low-Milage 41.2%	Mid-Milage 3%	High-Milage 2.5%
Marathon miles completed	% of participants	Completed 1.5%	Not Completed 98.5%		
Time to complete a marathon	% of participants	None 98%	Moderate 1%	Slow 1%	
Half-marathon miles completed	% of participants	Completed 2.5%	Not Completed 97.5%		
Time to complete half-marathon	% of participants	None 94.9%	Fast 2%	Moderate 2.5%	Slow 0.5%

Figure 1: Stroop Color and Word Test

Figure 2: Corsi Block-Tapping Test

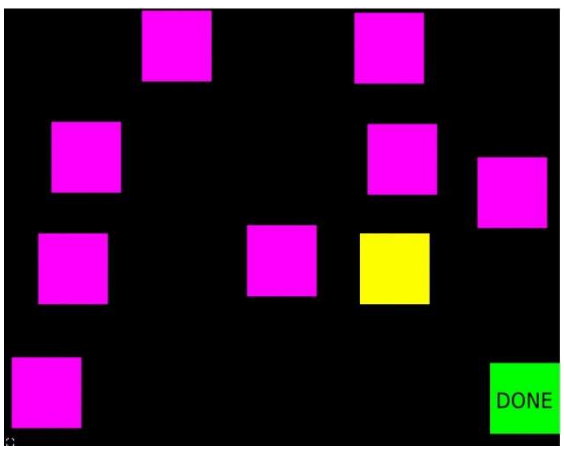
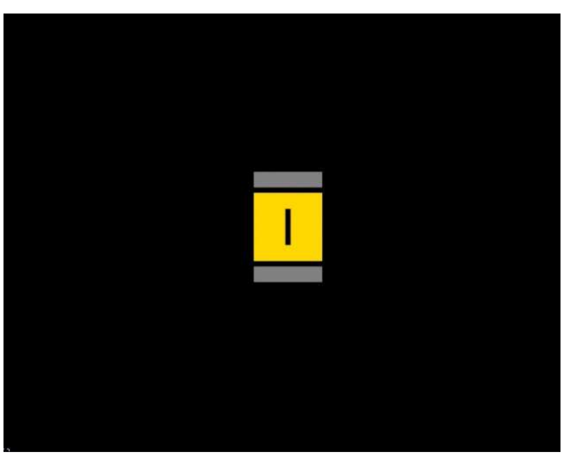


Figure 3: 2-Back Task



Results

Participants

Initially, the study produced 281 individual data sets. After the data were cleaned, the total number of participants was 199. Data sets were deleted based on the following criteria: incompletion, incorrectly answered attention check questions, and attempts completed after the first were deleted for participants that completed the survey more than once. The participant age range was from 18 to 61 years of age with a mean of 21 ± 5.3 years. Eighty-two participants were male (41.2%), and 117 participants were female (58.8%). The participants self-reported race as follows: 6 Asian (3%), 52 Black or African American (26.1%), 10 mixed races (5%), 130 White (65.3%), and 1 other than these options (0.5%).

Running Classifications

Participants were classified into groups based on the reported number of days ran, miles ran per week, marathon miles completed, completion time for marathons (if applicable), half-marathon miles completed, and completion time for half-marathons (if applicable). The number of days ran was classified into four groups and included none (0 days), low (1 - 2 days), moderate (3 - 4 days), and high (5 or more days). The miles ran per week were classified into four groups and included no miles (0 miles), low-miles (1 - 10 miles per week), mid-miles (11 - 25 miles per week), high-miles (26 or more miles per week). The number of marathon miles completed was either classified as a yes (26 or more miles ran at once) or no (less than 26 miles ran at once). The marathon completion time was classified into three groups and included none (invalid time or nothing listed), slow (4.1 or more hours), and moderate (3.1 - 4.0 hours). The number of half-marathon miles completed was either classified as a yes (13 or more miles ran at once) or no (less than 13 miles ran at once). The reported half-marathon completion times were classified into four groups and included none (invalid time or nothing listed), slow (2.1 or more hours), moderate (1.6 – 2.0 hours), and fast (1.0 – 1.5 hours).

Stroop Color and Word Test

The variables analyzed for the Stroop Color and Word Test did not have any significant correlations with running classification based on a two-tailed test ($p \leq 0.05$) using the Pearson Correlation analysis. Using a one-tailed test ($p \leq 0.1$) with the Pearson Correlation analysis, Stroop Color and Word Test correct matches and running days had a positive, weak correlation ($r = 0.123$, $n = 199$, one-tail $p = 0.042$, two-tail $p = 0.084$). Refer to Appendix I for all Stroop Color and Word Test correlations.

Corsi Block-Tapping Test

The following Corsi block-tapping test variables significantly correlated with various running classifications according to a two-tailed test ($p \leq 0.05$) using a Pearson Correlation analysis. Corsi highest score and running miles had a negative, weak relationship ($r = -0.155$, $n = 191$, $p = 0.033$). Refer to Appendix II for all Corsi block-tapping test correlations.

2-Back Task

The following 2-back task variables significantly correlated with various running classifications according to a two-tailed test ($p \leq 0.05$) using a Pearson Correlation analysis. The median reaction time of the 2-back task and running days had a negative, weak relationship ($r = -0.147$, $n = 194$, $p = 0.041$). The correct matches from the 2-back task and running miles had a positive, weak relationship ($r = 0.171$, $n = 194$, $p = 0.017$).

The misses from the 2-back task and running miles had a negative, weak relationship (r = -0.167, n = 194, p = 0.02). The misses from the 2-back task and running days had a negative, weak relationship (r = -0.151, n = 194, p = 0.036). The mean reaction time from the 2-back task and running days had a negative, weak relationship (r = -0.162, n = 194, p = 0.024). The mean reaction time from the 2-back task and running miles had a negative, weak relationship (r = -0.158, n = 194, p = 0.028). Refer to Appendix III for all 2-back task correlations.

Discussion

The purpose of this study was to determine if running was significantly related to cognitive functioning, especially the higher ordered functions of executive function. Specifically, the executive functions tested were cognitive inhibition, visuospatial short-term working memory, and working memory capacity. Overall, it was found that running positively effects executive function. This is reflected in the general improvement in cognitive test scores for runners as compared to non-runners, especially for cognitive inhibition and working memory capacity. Running volume, or milage, had a more significant correlation rather than the number of days ran due to a possible dose-response relationship.

Stroop Color and Word Test

Using a Pearson Correlation analysis, Stroop Color and Word Test correct matches and running days had a positive, weak correlation (r = 0.123, n = 199, one-tail p = 0.042, two-tail p = 0.084). A one-tailed test was utilized based on the hypothesis that the number of correct matches increases as running frequency increases. This study as well as previous research supports this hypothesis and outcome.

When moderate intensity aerobic exercise was implemented, the speed and accuracy of the Stroop Color and Word Test scores was improved (Douris, 2018). In a sample of healthy adults, this test was completed at a faster rate after a bout of high-intensity exercise (Burin, 2020). Thus, this demonstrates an improvement in executive functioning following various intensities and durations of exercise. The results of the current study expand on this by concluding that the specific exercise of running increases Stroop Color and Word Test scores. These test score improvements reflect better cognitive inhibition as the correlation assessed was overall score rather than reaction time. It was found that those who run more often will have more correct matches, thus a higher score, than those who do not undergo this type of exercise or run to a lesser degree.

Notably, the reaction time of naming the correct response is a more viable measurement rather than the accuracy of correct responses. This is because the Stroop Color and Word Test produces a ceiling effect when dependent on accuracy. Further, reaction time is dependent on exercise intensity and duration (McMorris, 2016). This was also observed in the current study, given that most participants scored the maximal score for accuracy. However, the reaction times varied. Thus, the reaction times for the Stroop Color and Word Test scores should be analyzed when examining the effects of running on cognitive function in healthy adults.

Corsi Block-Tapping Test

Corsi block-tapping test highest score and running miles had a negative, weak relationship (r = -0.155, n = 191, p = 0.033). This would indicate that as the number of miles a participant runs increases the Corsi block-tapping test highest score decreases. This relationship conflicts with the initial hypothesis that running will positively impact cognitive functioning. However, this correlation is weak, and there are limitations to this study that could contribute to this outcome. Generally, the literature supports the notion that physical activity improves cognitive functioning as well as improves Corsi block-tapping test scores.

In a study conducted with children, fitness levels significantly predicted Corsi block-tapping test scores. Additionally, the more fitness skills the child possessed, the higher the Corsi block-tapping test score was (Drozdowska, 2021). In a population of adults, Corsi block-tapping test scores improved after a sports exercise program in both participant groups, which were those with and without intellectual disabilities (Chen, 2019). The results of the current study found an inconclusive inverse relationship between Corsi block-tapping test scores and cognitive function. Thus, the effect of running on visuospatial short-term working memory cannot be established from this study alone. Further research is required to determine if there is a significant effect and if this relationship is weak across all conditions. The inverse relationship found in the current study cannot be readily explained, however, the contradictory finding here indicates that caution should be used when generalizing the positive relationship between physical activity and visuospatial short-term working memory across all exercise contexts. Therefore, more research in this area is needed to identify the conditions that facilitate a positive (or negative) relationship between physical activity and visuospatial short-term working memory.

2-Back Task

The 2-back task had the most correlations with running parameters, but all relationships found were relatively weak.

The number of days ran per weak correlated negatively with median reaction time (r = -0.147, n = 194, $p = 0.041$) and mean reaction time (r = -0.162, n = 194, $p = 0.024$). These results imply a decrease in reaction time as running increases. This supports the hypothesis because it suggests that reaction time becomes quicker as running volume increases. A study on younger and older adults also found that 2-back task reaction time was significantly improved in the group that underwent exercise (Hogan, 2018). The study on healthy adults by Kato (2018) discussed below also supports this conclusion.

The number of miles ran per week correlated positively with correct matches (r = 0.171, n = 194, $p = 0.017$). Similarly, the number of missed stimuli had a negative correlation with running miles (r = -0.167, n = 194, $p = 0.02$) and running days (r = -0.151, n = 194, $p = 0.036$). This indicates that as the number of miles a person runs increases, the 2-back task score will increase. This is supported by a study on older adults. The group that underwent aerobic training for six months had significantly higher 2-back task scores than the sedentary group (Jonasson, 2017). A study on a group of healthy adults also supports this conclusion and the last result of 2-back task mean reaction time and running miles that had a negative correlation (r = -0.158, n = 194, $p = 0.028$). The amount of time spent completing physical activity significantly correlated with 2-back task reaction time. Thus, an increased amount of physical activity increased 2-back task scores (Kato, 2018).

One plausible explanation for the differences between running days and running miles is the actual quantity of exercise. Running more miles in a week would produce more favorable outcomes for cognitive function rather than running a lower frequency of miles over the span of more days (i.e., running 15 miles in 3 days compared to running 5 miles in 5 days). Thus, a dose-response to exercise may play a role.

Overall, the results of the current study found that there is a general increase in working memory capacity, or 2-back task scores, in individuals who participate in running as a form of physical exercise. Further, there are more positive relationships between the number of miles ran and the improvement of working memory capacity.

Limitations and Future Research

One major limitation to this study was the diversity of running classifications. Although there was a relatively even split between runners and non-runners, the running milage posed limitations. This was due to most runners being classified as low milage (1-10 miles per week). Specifically, 41.2% were low milage, 3% were medium milage (11-25 miles per week), and 2.5% were high milage (26 or more miles per week). The other 53.3% were non-runners. As noted, there were significantly less individuals who ran further distances. This may be a reason as to why all of the significant correlations were weak. A more even separation between runners is needed to result in stronger correlations that could produce better inferences.

Another plausible explanation of the weak correlations may be due to a dose-response to exercise on cognitive function, and therefore, warrants for further research on this relationship. A study on resistance exercise found that as exercise intensity increased, executive function increased. Notably, the Stroop Color and Word Test was used to assess cognitive function, which is similar to the current study. It was stated that resistance and aerobic exercise is beneficial to executive function, especially at increasing intensities. According to the study, the specific cognitive functions that are improved with increasing exercise intensity are inhibition, selective attention, shifting ability, control of task relevant information, working memory, and information processing (Chang, 2009). These factors, such as inhibition and working memory, were also assessed in the current study. If there were more individuals with an increased running milage, these factors could aid in showing a stronger relationship between variables.

Notably, the duration of exercise is an important consideration for the effects on executive function. Specifically, aerobic exercise (running) was investigated in the current study, and there may be an ideal duration for cognitive improvements which requires further research. This may also explain why the cognitive improvements in the current study were not profoundly significant as most runners endured short mileages in addition to half of the participants being non-runners. Previous literature on this type of exercise in relation to duration and cognitive function has shown a delicate balance for this aspect. It was found that the ideal duration for moderate-intensity aerobic exercise was twenty minutes. Furter, durations of ten minutes or less and forty-five minutes or more showed no benefits to cognitive function. Although highly trained individuals may experience cognitive function improvements from longer durations, they still have a period of decreased cognition due to the stress on the body. On the other hand, normally trained and nontrained individuals experience this general decrease in relation to duration. Notably, the twenty-minute exercise period is ideal especially for higher-order cognitive function, such as executive function. This is mainly due to an increase in arousal leading to an increase in attention (Chang, 2015).

A more recent study on the dose-response relationship between acute exercise duration and cognitive function highlighted its benefits to inhibition, cognitive flexibility, spatial working memory, and processing speed, which were executive function components explored in the current study. The participants in the study by Salerno (2020), breast-cancer patients, experienced cognitive improvements when walking ten to thirty minutes. Therefore, the window of optimal exercise duration appears to be variable but could be optimized within this ten-to-thirty-minute range in order to produce the most benefits. It was also noted that excessively long durations lead to a decrease in cognitive function due to factors such as dehydration and substrate depletion. Exercise duration could also be dependent on physiological characteristics of individuals (Salerno, 2020). Overall, previous literature has shown that an optimal window for cognitive improvements exists. Although this requires further research, it is likely that the participants in the current study may have missed this window due to their low durations of running, resulting in less significant improvements in cognitive test scores between runners and non-runners.

Conclusion

It was hypothesized that running would improve overall executive function as compared to those who do not regularly run. Specifically, the executive functions assessed were cognitive inhibition, visuospatial short-term working memory, and working memory capacity. This study concluded that running does have beneficial effects on executive function. Specifically, cognitive inhibition and working memory capacity had relationships that support this notion. On the other hand, visuospatial short-term working memory assessed by the Corsi block-tapping test had an inconclusive contradictory relationship. The current study also contributes to the ceiling effect produced by the Stroop Color and Word Test. Because of this phenomenon, it is advised that the Stroop Color and Word Test reaction time should be analyzed rather than its accuracy for more conclusive results. The findings of the current research in addition to previous literature also suggests a dose-response relationship of running to cognitive function. While various forms of exercise have been shown to generally improve health parameters, this study suggests that running specifically has a positive impact on cognitive health.

Overall, this study was more comprehensive than many other previous studies because it included three cognitive tests, rather than only using one. This provided data that expands on the types of executive functions affected by exercise. The focus of this study also provided an important expansion on the type of exercise that affects cognitive function. Running was the only form of exercise explored, which is a more specific form of exercise. Thus, individuals have a more exact exercise guideline to follow. Further, the effects of running on cognitive function were not examined immediately before or after a run. This is beneficial to understanding the chronic effects of running on cognitive function.

On a larger scale, running, or aerobic exercise, is beneficial to not only physiological health but also to cognitive health. This poses a non-pharmaceutical intervention for those with and without mental deficits seeking improvements to executive function.

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Appendix I: Stroop Color and Word Test Correlations

Correlations				
		Stroop_Pct_Correct	Stroop_Mean_Response_Time	Stroop_Median_Response_Time
2_Back_Median_Rxn_Time	Pearson Correlation	0.088	0.003	0.017
	Sig. (2-tailed)	0.22	0.966	0.81
	N	194	194	194
RunningDays	Pearson Correlation	0.123	0.026	0.075
	Sig. (2-tailed)	0.084	0.71	0.29
	N	199	199	199
RunningMiles	Pearson Correlation	0.087	-0.005	0.021
	Sig. (2-tailed)	0.221	0.948	0.764
	N	199	199	199
MarathonMiles	Pearson Correlation	0.006	-0.014	-0.007
	Sig. (2-tailed)	0.936	0.848	0.927
	N	199	199	199
HalfMarathonMiles	Pearson Correlation	0.006	-0.017	-0.01
	Sig. (2-tailed)	0.928	0.81	0.893
	N	199	199	199
MarathonTime	Pearson Correlation	0.06	-0.011	-0.009
	Sig. (2-tailed)	0.397	0.876	0.898
	N	199	199	199
HalfMarathonTime	Pearson Correlation	0.049	-0.024	-0.027
	Sig. (2-tailed)	0.49	0.732	0.703
	N	199	199	199
Stroop_Pct_Correct	Pearson Correlation	1	-0.099	-0.092
	Sig. (2-tailed)		0.162	0.195
	N	199	199	199
Stroop_Mean_Response_Time	Pearson Correlation	-0.099	1	0.078
	Sig. (2-tailed)	0.162		0.271
	N	199	199	199
Stroop_Median_Response_Time	Pearson Correlation	-0.092	0.078	1
	Sig. (2-tailed)	0.195	0.271	
	N	199	199	199
Corsi_Highest	Pearson Correlation	0.055	-0.087	0.053
	Sig. (2-tailed)	0.45	0.23	0.464
	N	191	191	191
Corsi_number_before_miss	Pearson Correlation	0.113	-0.014	-0.004
	Sig. (2-tailed)	0.12	0.843	0.956
	N	191	191	191
2_Back_Pct_Type	Pearson Correlation	0.082	0.09	-0.073
	Sig. (2-tailed)	0.255	0.211	0.314
	N	194	194	194
2_Back_Pct_Correct_Match	Pearson Correlation	.246**	-0.066	-0.077
	Sig. (2-tailed)	0.001	0.361	0.283
	N	194	194	194
2_Back_Pct_Miss	Pearson Correlation	-.218**	0.126	0.041
	Sig. (2-tailed)	0.002	0.08	0.571
	N	194	194	194
2_Back_Pct_False_Alarm	Pearson Correlation	-0.006	-0.03	-0.026
	Sig. (2-tailed)	0.935	0.677	0.723
	N	194	194	194
2_Back_Mean_Rxn_Time	Pearson Correlation	-0.036	0.067	0.067
	Sig. (2-tailed)	0.62	0.352	0.353
	N	194	194	194

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Appendix II: Corsi Block-tapping Test Correlations

Correlations			
		Corsi_Highest	Corsi_number_before_miss
2_Back_Median_Rxn_Time	Pearson Correlation	0.021	0.042
	Sig. (2-tailed)	0.78	0.571
	N	186	186
RunningDays	Pearson Correlation	-0.11	0.049
	Sig. (2-tailed)	0.13	0.502
	N	191	191
RunningMiles	Pearson Correlation	-.155*	-0.01
	Sig. (2-tailed)	0.033	0.894
	N	191	191
MarathonMiles	Pearson Correlation	-0.075	-0.013
	Sig. (2-tailed)	0.303	0.854
	N	191	191
HalfMarathonMiles	Pearson Correlation	-0.075	-0.021
	Sig. (2-tailed)	0.302	0.769
	N	191	191
MarathonTime	Pearson Correlation	-0.129	-0.025
	Sig. (2-tailed)	0.075	0.729
	N	191	191
HalfMarathonTime	Pearson Correlation	-0.096	0.049
	Sig. (2-tailed)	0.184	0.501
	N	191	191
Stroop_Pct_Correct	Pearson Correlation	0.055	0.113
	Sig. (2-tailed)	0.45	0.12
	N	191	191
Stroop_Mean_Response_Time	Pearson Correlation	-0.087	-0.014
	Sig. (2-tailed)	0.23	0.843
	N	191	191
Stroop_Median_Response_Time	Pearson Correlation	0.053	-0.004
	Sig. (2-tailed)	0.464	0.956
	N	191	191
Corsi_Highest	Pearson Correlation	1	.512**
	Sig. (2-tailed)		0
	N	191	191
Corsi_number_before_miss	Pearson Correlation	.512**	1
	Sig. (2-tailed)	0	
	N	191	191
2_Back_Pct_Type	Pearson Correlation	-0.045	-0.012
	Sig. (2-tailed)	0.543	0.876
	N	186	186
2_Back_Pct_Correct_Match	Pearson Correlation	-0.008	0.111
	Sig. (2-tailed)	0.909	0.13
	N	186	186
2_Back_Pct_Miss	Pearson Correlation	-0.016	-0.115
	Sig. (2-tailed)	0.827	0.119
	N	186	186
2_Back_Pct_False_Alarm	Pearson Correlation	0.019	0.059
	Sig. (2-tailed)	0.794	0.423
	N	186	186
2_Back_Mean_Rxn_Time	Pearson Correlation	0.006	-0.07
	Sig. (2-tailed)	0.94	0.34
	N	186	186
* Correlation is significant at the 0.05 level (2-tailed).			
** Correlation is significant at the 0.01 level (2-tailed).			

Appendix III: 2-back Test Correlations

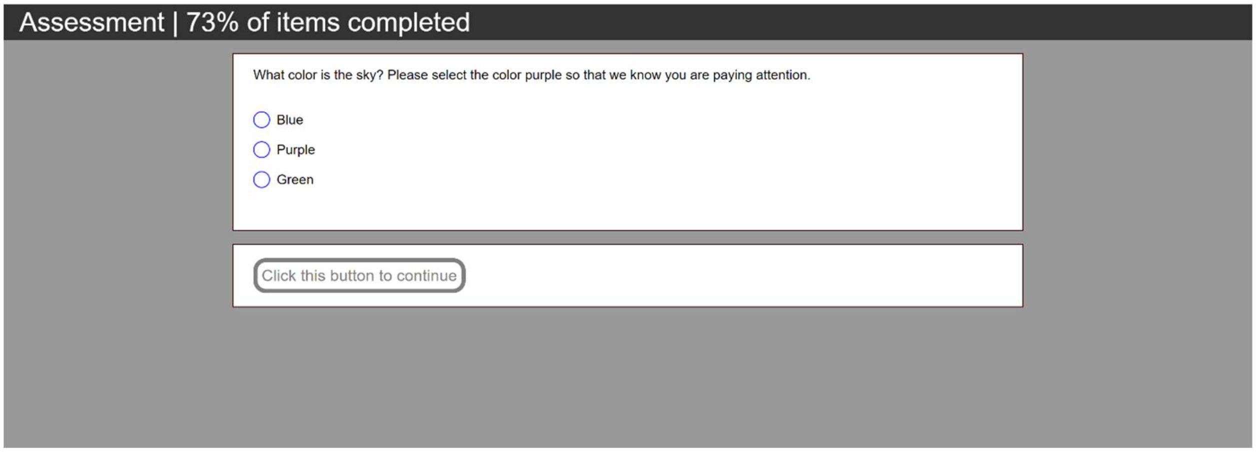
Correlations						
		2_Back_Pct_Type	2_Back_Pct_Correct_Match	2_Back_Pct_Miss	2_Back_Pct_False_Alarm	2_Back_Mean_Rxn_Time
2_Back_Median_Rxn_Time	Pearson Correlation	-0.057	-.198**	.179*	0.017	.602**
	Sig. (2-tailed)	0.433	0.006	0.012	0.816	0
	N	194	194	194	194	194
RunningDays	Pearson Correlation	0.007	0.141	-.151*	-0.057	-.162*
	Sig. (2-tailed)	0.928	0.051	0.036	0.432	0.024
	N	194	194	194	194	194
RunningMiles	Pearson Correlation	0.027	.171*	-.167*	-0.033	-.158*
	Sig. (2-tailed)	0.713	0.017	0.02	0.647	0.028
	N	194	194	194	194	194
MarathonMiles	Pearson Correlation	0.052	0.064	-0.031	-0.008	-0.066
	Sig. (2-tailed)	0.472	0.377	0.664	0.911	0.361
	N	194	194	194	194	194
HalfMarathonMiles	Pearson Correlation	0.045	0.062	-0.033	-0.009	-0.06
	Sig. (2-tailed)	0.534	0.393	0.644	0.897	0.408
	N	194	194	194	194	194
MarathonTime	Pearson Correlation	0.076	0.105	-0.062	-0.015	-0.066
	Sig. (2-tailed)	0.292	0.145	0.394	0.838	0.359
	N	194	194	194	194	194
HalfMarathonTime	Pearson Correlation	0.05	0.119	-0.096	-0.02	-0.102
	Sig. (2-tailed)	0.487	0.098	0.182	0.784	0.156
	N	194	194	194	194	194
Stroop_Pct_Correct	Pearson Correlation	0.082	.246**	-.218**	-0.006	-0.036
	Sig. (2-tailed)	0.255	0.001	0.002	0.935	0.62
	N	194	194	194	194	194
Stroop_Mean_Response_Time	Pearson Correlation	0.09	-0.066	0.126	-0.03	0.067
	Sig. (2-tailed)	0.211	0.361	0.08	0.677	0.352
	N	194	194	194	194	194
Stroop_Median_Response_Time	Pearson Correlation	-0.073	-0.077	0.041	-0.026	0.067
	Sig. (2-tailed)	0.314	0.283	0.571	0.723	0.353
	N	194	194	194	194	194
Corsi_Highest	Pearson Correlation	-0.045	-0.008	-0.016	0.019	0.006
	Sig. (2-tailed)	0.543	0.909	0.827	0.794	0.94
	N	186	186	186	186	186
Corsi_number_before_miss	Pearson Correlation	-0.012	0.111	-0.115	0.059	-0.07
	Sig. (2-tailed)	0.876	0.13	0.119	0.423	0.34
	N	186	186	186	186	186
2_Back_Pct_Type	Pearson Correlation	1	.419**	.172*	0.086	-.304**
	Sig. (2-tailed)		0	0.017	0.233	0
	N	194	194	194	194	194
2_Back_Pct_Correct_Match	Pearson Correlation	.419**	1	-.817**	0.088	-.789**
	Sig. (2-tailed)	0		0	0.224	0
	N	194	194	194	194	194
2_Back_Pct_Miss	Pearson Correlation	.172*	-.817**	1	-0.05	.660**
	Sig. (2-tailed)	0.017	0		0.49	0
	N	194	194	194	194	194
2_Back_Pct_False_Alarm	Pearson Correlation	0.086	0.088	-0.05	1	-0.053
	Sig. (2-tailed)	0.233	0.224	0.49		0.464
	N	194	194	194	194	194
2_Back_Mean_Rxn_Time	Pearson Correlation	-.304**	-.789**	.660**	-0.053	1
	Sig. (2-tailed)	0	0	0	0.464	
	N	194	194	194	194	194

* Correlation is significant at the 0.05 level (2-tailed).

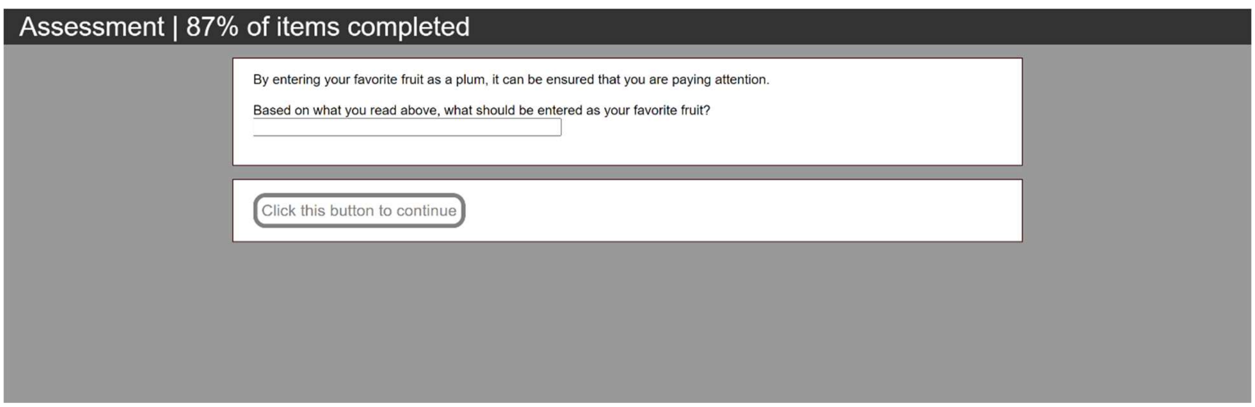
** Correlation is significant at the 0.01 level (2-tailed).

Appendix IV: Attention Check Questions

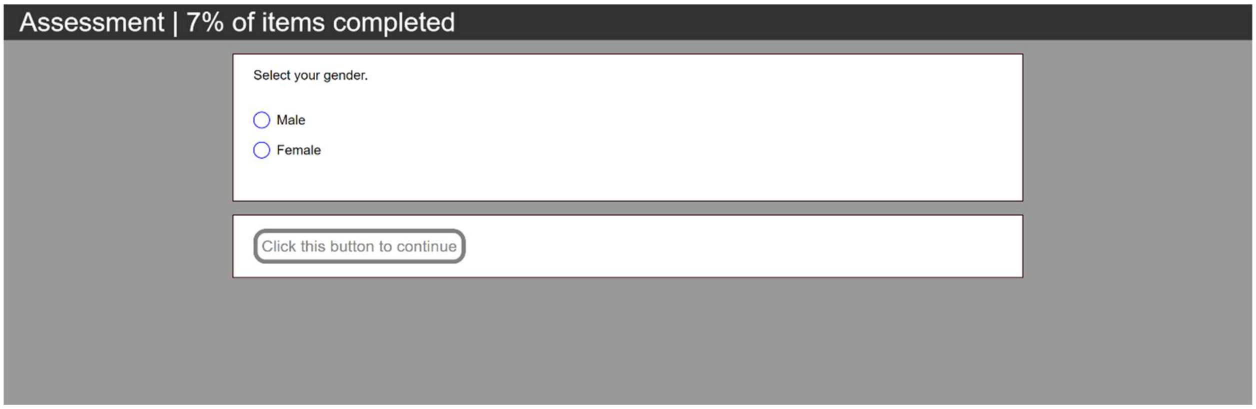
Question 1:

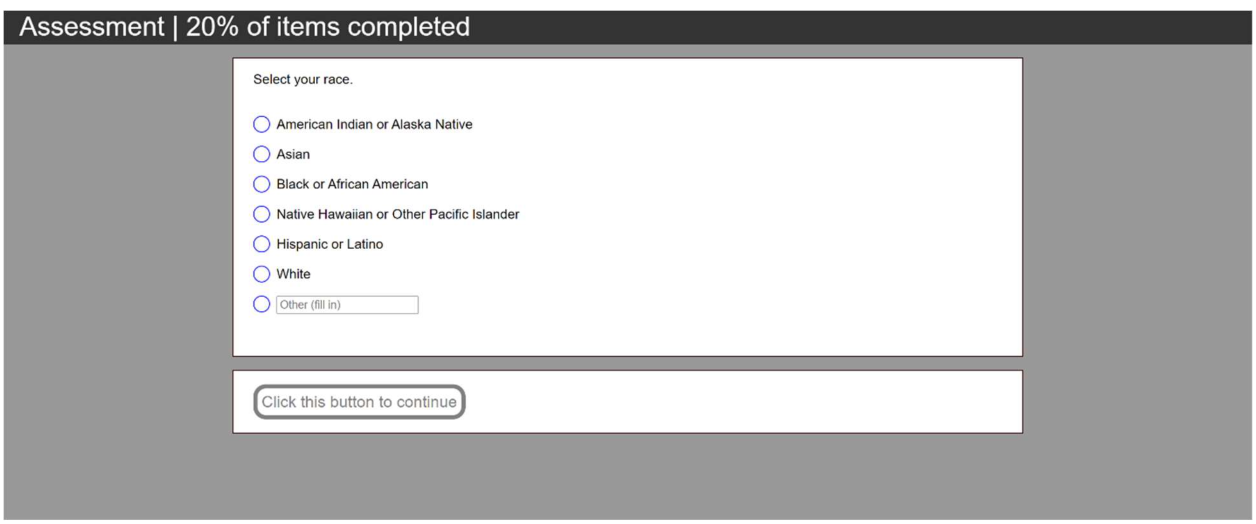


Question 2:



Appendix V: Demographics Questions





Assessment | 27% of items completed

How many days per week do you run (on average)?

Days:

If you do not regularly run, enter "N/A" here:

Click this button to continue

Assessment | 33% of items completed

How many miles per week do you run (on average)?

Miles:

If you do not regularly run, enter "N/A" here:

Click this button to continue

Assessment | 33% of items completed

How many miles per week do you run (on average)?

Miles:

If you do not regularly run, enter "N/A" here:

Click this button to continue

Assessment | 33% of items completed

How many miles per week do you run (on average)?

Miles:

If you do not regularly run, enter "N/A" here:

Click this button to continue

Assessment | 33% of items completed

How many miles per week do you run (on average)?

Miles:

If you do not regularly run, enter "N/A" here:

Click this button to continue

Assessment | 33% of items completed

How many miles per week do you run (on average)?

Miles:

If you do not regularly run, enter "N/A" here:

Click this button to continue

Appendix VI: Informed Consent

UL Lafayette IRB approval number: __________

You are being invited to participate in a research project by Dr. Gregg Davis and Lauren Bainter from the University of Louisiana at Lafayette. The purpose of this study is to determine if marathon runners have better executive cognitive functions than those who do not participate in marathons. We expect this study to last about one year and will collect data from fifty people.

You will be asked to engage in a series of three cognitive tests, which will be completed at one time. Each test will take around two minutes to five minutes, totaling about nine minutes.

The only expected risk to you for taking part in this study is the loss of time it takes to take the cognitive tests.

The benefit to you is learning your scores on certain aspects of executive functioning. This study will help researchers and professionals understand the cognitive effects of long-distant running. Participants who complete the tests will be entered into a drawing for a chance to win a ten-dollar Amazon gift card. Ten prizes will be awarded at the conclusion of the test and will be sent electronically.

The results of this research may be published in professional journals but no personal information about any of the people who participated will be part of any of the reports. The cognition tests are run through psytoolkit, an online platform. No identifiable information will be collected on the tests.

You are not required to participate in this research. It is your choice whether to be a part of the study or not. You may decide to not be a part of the study, even if you have begun to take the tests. There will be no bias or penalty from University of Louisiana at Lafayette or the State of Louisiana, if you decide not to participate or if you decide to stop participating in the research.

If you have any questions about this research or your participation in the study, you are welcome to call Dr. Gregg Davis at 337-482-6615 or Gregg.davis@louisiana.edu and/or Ms. Lauren Bainter 337-351-9699 or Lauren.bainter1@louisiana.edu at UL Lafayette. We will make every effort to answer your questions. If you have any questions about your rights as a research participant, please contact the Chair of UL Lafayette Institutional Review Board (IRB), Dr. Hung-Chu Chin, at irb@louisiana.edu or 337-482-5811. The primary purpose of the UL Lafayette IRB is to protect the rights and welfare of human subjects involved in research activities being conducted at UL Lafayette.

CONSENT

I understand that I am participating in research and that the research has been explained to me so that I understand what I am doing. I understand that I may stop participating at any time.

Signed____Date________________

Witness ____Relationship if any____________

Reason for witnessing the form (ex: unable to read, signs with X)_________________________

Reviewed and approved by the Chair and Vice-Chair of the IRB 3-25-2020

Appendix VII: IRB Approval

UNIVERSITY OF LOUISIANA Lafayette

Institutional Review Board

IRB registration 00001474
Federal Wide Assurance 00000758

to: Dr. Gregg Davis

from: Hung-Chu Lin, IRB Chair

re: Approval of Proposal: FA20-18 KNES

date: 10/20/2020

Project Title: Executive and cognitive function in distance runners
Review Level: Expedited
IRB Determination: Approved
Approval Number: FA20-18 KNES

Congratulations, you may begin collecting data.

Yearly reviews are not required for Expedited proposals.

If you need to make any changes in your data collection procedures, treatments, or subject population before the end of the approval period, please submit the changes for review to the IRB prior to implementation.

If there is any type of injury to any participant of this research you must notify the IRB within 24 hours, via the Adverse Event Form. Failure to inform the IRB of injury to participants is grounds for suspension of the research.

When your project is complete, please complete the Project Closure Form.

We wish you well with your project. If you have any questions about revisions and the need for re-review, please contact the IRB at irb@louisiana.edu.

from the desk of:
IRB Chair
University of Louisiana at Lafayette
P.O. Box 43610
Lafayette, LA 70504-3610
(337) 481-5811
email: irb@louisiana.edu