THE EFFECTS OF CARDIOVASCULAR STRESS ON COGNITION

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LIST OF ABBREVIATIONS

SC = Sedentary Control

MCS = Moderate Cardiovascular Stress

RFT = Reversible Figure Test

ST = Stroop Color-Word Task

RDS = Reverse Digit Span Test

STM = Short-term Memory

DS = Digit Span

HRR = Heart Rate Reserve

THR = Target Heart Rate

ABSTRACT

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Human beings are frequently exposed to significant levels of psychological and physical stress. How stress is perceived determines the positive (eustress) and negative (distress) effects it can have on someone. This research looked at the effect of moderate cardiovascular stress on three cognitive functions. The procedure measured changes in directed attention using the reversible figure test (RFT), response inhibition using the Stroop test (ST) and short term memory using the reverse digit span test (RDS). This test determined that moderate cardiovascular demand is either eustressful or distressful depending on the cognitive function. Fifty-seven undergraduate students or similar volunteers were used in the study. Participants were in either a sedentary control condition (SC) or a moderate cardiovascular stress condition (MCS). All participants completed the cognitive measures three times. Maximal heart rate reserve (HRR) was calculated for each participant and in the moderate cardiovascular stress condition the participants maintained a target heart rate between 45% and 55% of their HRR. A repeated-measures analysis of variance (rmANOVA) was used to analyze the data for each cognitive measure separately. Participants in the MCS condition were less attention fatigued ($\bar{x}$ = 19.747) than the SC condition ($\bar{x}$ =

20.476). Short-term memory was significantly better in the SC condition ($\bar{x}$ = 6.813) than the MCS condition ($\bar{x}$ = 6.381). The results from the Stroop Color-Word Task was significantly different in the SC condition ($\bar{x}$ = -0.543) than the MCS condition ($\bar{x}$ = 2.019), but a procedural error in the MCS condition obscured the true ST scores. MCS stress has important effects on cognition, but the mechanisms at play are still not well understood.

Keywords: cardiovascular stress, cognition, Stroop, heart rate reserve

INTRODUCTION

Statement of the Problem

Human beings are frequently exposed to significant levels of psychological and physical stress. Selye (1976) defines stress as a nonspecific response of the body to any demand. Some stress can be productive and positive. This type of demand is sometimes called eustress. Edwards and Cooper (1988) defined eustress as a positive difference between an individual’s perception and desires, given that the difference is significant to the individual. This difference leads to increased effort, or efficiency and better performance. In contrast, distress is defined as a negative difference between an individual’s perception and desires, given that the difference is also significant to the individual. This difference leads to decreased effort, or inefficiency and worse performance.

It is important to recognize eustress and distress as separate and independent aspects of an individual’s overall stress response. Eustress is a result of an individual’s positive perception of situation demands; distress is a result of an individual’s negative perception of situation demands. Both eustress and distress can occur in the presence of a stressor, such as public speaking. For some, speaking in front of a group of people can be quite distressful. However, the same stressor of speaking in front of a group of people can be perceived as eustress in another individual. How stress is perceived determines the positive and negative effects it can have on someone. Eustress and distress define experiences, not situations. It would be inappropriate to label public speaking, a situation, as a eustressful or distressful stressor. To varying degrees the outcome of stress is determined by an individual’s perception of the amount of demand, the source of the demand, the timing of the demand, the degree to which an individual feels personal control over the demand, and, finally, whether or not the demand is of a desirable nature (Nelsons and Simmons, 2003). A given environmental demand creates eustress or distress based on the individual’s sense of these attributes. A situation is perceived as distressing if the timing is inconvenient, the source of the demand is problematic, the demand of the stressor is not desirable and the individual perceives a lack of control over the situation (Le Fevre et al., 2003). The desirability of the demand is important in how humans perceive and take action in any stressful situation. For some, a more demanding stressor can be perceived as more desirable. Some individuals thrive under stringent circumstances. Bomb squads are put in incredibly demanding situations. However, bomb disposal technicians desire that level of demand, and perform optimally given their circumstances.

Many outcomes may be changed by stress. Physiological effects of stress are well understood. For example, continuous distress increases heart disease (Cuesta & Singer, 2012). On the other hand, appropriate physical eustress is beneficial. Regular physical exercise has been seen to irrefutably improve quality of life in numerous ways, such as preventing cardiovascular disease, obesity, cancer, diabetes, hypertension, osteoporosis, and depression (Warburton, Nicol, & Bredin, 2006). While the effect of eustress on the body is well researched, and supported by many empirical tests, the mechanisms by which these “eustressors” improve fitness and help the body are not well known (Selye, 1976). Thus, it is hard to predict which situation will be eustressful versus distressful. Further, the effects of stress on human cognition are even less well understood. Developing a more detailed understanding of how stress changes human cognitive function may help differentiate between positive eustressful situations and negative distressing circumstances.

Human cognition is central to gathering, selecting, processing, and storing vital information for our daily lives. Cognition is a complex set of critical functions. The central role of cognition can be seen if we consider the importance of just three specific functions: attention, central control of response choice, or response inhibition, and short term memory.

Attention is used to manage the enormous amount of information received at every moment. Attention determines which information from the environment enters our awareness (Merikle & Joordens, 1997). Beyond attending to information cognition's central executive decides how and when to respond. Some responses are judged to be appropriate and others are inhibited. Finally, some situations are processed immediately, but in other cases information is retained for later use. When this retention interval is brief, short term memory is an adequate storage option.

Thus, a productive question may be, "How does stress change these three fundamental functions of human cognitive performance?" If stress is a source of arousal then the Yerkes-Dodson Law (1908) suggests that stress will change performance. When a person is in a state of complete rest that individual will perform at a sub-optimal level. As demand and arousal increase, there is a then a period of increasing performance. Finally, the situation can become so demanding that performance begins to fail. This non-monotonic relationship between arousal and performance has been well documented (Watters et al., 1997).

While Yerkes-Dodson refers specifically to the relationship between arousal and performance, since stress produces arousal, it is reasonable to extend this concept to stress. In considering stress, there are certainly differences between physical and psychological stress. However, perhaps these two types of stress can be mapped onto each other. Consider the physiological and performance changes with each type of stress.

Both types of stress have a significant physiological impact. Physical stress changes performance as described above. Further, psychological stress certainly affects performance and cognitive function. What is less well defined is how physical stress affects cognitive performance.

Does the Yerkes-Dodson Law describe the relationship between physical stress and cognitive function? Specifically, would an increase in cardiovascular stress change cognitive functioning?

This research will look at the effect of moderate cardiovascular stress on three cognitive functions. The procedure will measure changes in directed attention using the reversible figure test (RFT) and response inhibition using the Stroop test (ST). The test will also measure short term memory using the reverse digit span test (RDS). This test will determine whether moderate cardiovascular demand is eustressful or distressful for ongoing cognitive function.

REVIEW OF THE LITERATURE

Psychological Stress: Sources and Effects

Psychological sources of stress include performance demand, emotional state, and environmental stress (e.g. threat or pain). As noted above, psychological stressors can be perceived as eustress and distress.

The stress of performance demand varies as a function of perceived demand, source, timing and the control that the individual has over the stressor (Le Fevre et al., 2003). Consider each of these attributes.

Imagine a pitcher throwing during batting practice versus pitching at the end of a critical game. In the two situations, the actual physical activity is more similar than different. However, the experienced stress is dependent on how the pitcher perceives the performance demand. Most people have low expectations of the pitcher during batting practice and lofty expectations during a critical game. If the performer shares these expectations about performance, then batting practice is not as stressful. However, if the pitcher believes that his performance at practice is critical, then that situation becomes demanding and stressful. The situation is still just practice, but the pitcher perceives the demand differently, thus the task becomes more stressful.

The stress accompanied by emotional state is another aspect of the greater stressor picture. In perceiving stress as positive (eustress) or negative (distress), emotional state is important in distinguishing one from the other. Imagine an individual who is the spokesperson for a rising company. The person’s job requires work in public relations, often times pitching the company to large groups of important people. This person is proficient in public speaking and thrives on the demand each marketing pitch requires. However this all changes when the speaker loses a close loved one to an illness. The person’s emotional state is volatile adding stress to an already stressful occupation. During this emotional time, the person finds it hard to manage the stress of life. While this example is outlining the effect of a negative emotional state on stress, the inverse is easy to illustrate as well. If this individual recently got promoted, the resulting emotional state is highly positive, and other stressors can become eustressful.

The stress produced by environmental threat also depends upon the individual’s perspective. Imagine a fast paced action scene from a blockbuster film where the protagonist risks life and limb to chase a bad guy. The hero has to navigate an environment filled with dense traffic, claustrophobic alleyways, treacherous rooftops, and possibly speeding trains all to chase down the criminal. The environment poses a threat in an already stressful situation. The perspective of the hero will determine whether the stress thrust upon him is distressful or eustressful. Since action heroes relish the performance demand of a good chase the “threatening” environment is actually experienced as an opportunity not a danger. In contrast, chasing the same criminal through wide open country with sweeping green fields may not seem to be an environmental “threat”, but an action star may not enjoy the task in that setting, thus the “safe” place is distressful. Finally, consider the hero’s response, when is it good and exciting and when it is boring and bad, and that predicts performance as described by the Yerkes-Dodson Law.

It should come as no surprise, but psychological stress can have a large effect on cognition. The common assumption about psychological stress is that mild amounts of psychological stress can facilitate cognitive function and performance. However, too much stress can be detrimental to cognition (Sandi, 2013).

On the mild psychological stress side of cognition, Parker et al. (2005) found that presenting mildly stressful experiences early to young monkeys improved prefrontal-dependent response inhibition.

However, too much psychological stress can have a negative effect on cognition. Researchers have seen this in people suffering from post-traumatic stress disorder (PTSD). Controlling for trauma related changes in cognition, Qureshi et al. (2011) reviewed 21 articles from 1968 to 2009 concerning cognition studies on people with PTSD and people who were exposed to trauma, but did not have PTSD. They found that people with PTSD showed greater cognitive impairments than those who had suffered trauma, but were not diagnosed with PTSD.

Physical Stress: Sources and Effects

Various physical demands have been shown to act as stressors. The literature on the effects of aversive environmental conditions such as heat, noise, and crowding is extensive. This study will focus on exercise induced stress and this review will only highlight several illustrative examples of other sources of physical stress.

Aversive environmental conditions can produce a stress response. Iguchi, Littman, Wester, Knipper and Sheild (2012) found that whole body heating produced physiological responses that looked like exercise stress. Crandall & Gonzalez (2010) found that heat stress, whether induced by exercise or by elevated environmental temperatures results in markedly pronounced cardiovascular changes that are necessary in temperature regulation and muscle profusion.

Noise can be considered a major environmental stress that is paramount to the neural mechanisms of threat perception. The inner ear is directly connected to the “fight or flight” response associated with the autonomic nervous system (Westman & Walters, 1981). Smith et al. (2004) looked at the physiological effects of noise on goldfish. They found that while there was no long-term physiological stress response, there was a brief change in plasma cortisol levels after ten minutes of exposure to the noise. Kirschbaum & Hellhammer (1998) suggest that noise can affect hypothalamic-pituitary-adrenal (HPA) function and cortisol levels, further proposing that noise may contribute to allostatic load. Melamed & Bruhis (1996) found that healthy industrial workers chronically exposed to high ambient noise levels (>85 dB) without protective equipment covering their ears showed higher cortisol levels than workers with ear protection.

Every time someone says, “Let’s leave early so we can avoid the crowds.” there is an implied message. Crowds are bad. A crowded environment can be threatening and stressful to people and animals. Armario, Castellanos & Balasch (2008) found that high density or crowding increased emotional reactivity in rats. The corticotropin response to noise in a crowded condition was higher than in the less crowded control condition.

Of course, some individuals find a higher level of excitement in crowds. For them crowding is eustressful. This matches arousal theory which argues that some people require a higher level of arousal (Berlyne, 1960). For example, Baker & Wakefield (2012) found that there are social mall shoppers who relish high density environments and there are task-oriented shoppers, or the “get in-get out” shoppers who experience higher amounts of stress in crowded situations.

The current study is specifically interested in physical exercise as a stressor. Again, it is possible that in some cases exercise will be eustressful and in others distressful. This dichotomy is obvious in the literature.

For example, short term exercise may not act as a distressful event. Moorthy & Zimmerman (1978) found that cardiovascular stress, produced through exercise, increased plasma cortisol levels. However, this change only followed intensive, prolonged exercise like marathon running. Landman et al. (1984) found a similar result when short-term exercise did not increase plasma cortisol levels. Weinstock, Barry & Petry (2008) found a positive impact of exercise on treating people suffering from substance abuse. Weinstock et al.

found that substance-abusers who engaged in exercise-related activities, as part of their treatment, reported longer durations of abstinence than participants who did not. Belardinelli, Georgiou, Cianc, & Purcaro (1999) observed positive outcomes of long-term moderate exercise training (ET) on people who suffer from chronic heart failure (CHF). The moderate exercise group underwent an initial eight weeks of ET, exercising for three times a week at 60% of peak Vo_2, followed by a year of ET twice a week. The control group did not exercise during this period. Reported “quality of life”, assessed from a questionnaire, improved in participants in the exercise condition. ET was associated with lower mortality rate and hospital readmission for heart failure.

Physical exercise can even be used for stress reduction. Crews and Landers (1987) suggest that aerobic exercise can be a practical intervention for controlling the physiological stress response. This is especially useful when this response is “pathological hypersympathetic arousal.” Steptoe & Butler (1996) studied adolescents’ reactivity to emotional distress while engaging in vigorous physical exercise. Adolescents who participated in the vigorous physical exercise condition showed less emotional distress than non-exercise control groups.

It is clear that psychological stress changes both physiological and cognitive functions. It is also clear that physical stress changes physiological functions. It is less clear how physical stress changes cognitive function.

The effects of physical stress on cognition are inconsistent. Tomporowski & Ellis (1986) reviewed the literature on exercise and found that there was no empirical evidence to support that exercise has a positive impact on cognition.

Etnier et al. (1997) later found that benefits of short bouts of aerobic exercise were limited to improving simple reaction time in participants. This was more recently reviewed and confirmed by McMorris & Graydon (2000). According to McMorris & Graydon, only the speed of reaction time on automatic tasks can be increased by bouts of physical exercise. Hillman, Erickson, & Kramer (2008) found that physical exercise can have a positive impact on various brain functions and cognition, however, the mechanisms that make up this relationship is still unclear.

Kennedy and Scholey (2000) found that the participants with a heart rate less than the median performed significantly better on modified forms of Serial Sevens and Threes. In Sevens and Threes, participants continuously subtract seven or three from a random starting number. The task is quite cognitively demanding. This suggests that lower physical stress improves cognition.

In a more recent review of the literature, Tomporowski (2003) postulates that the literature on exercise has failed to find a succinct relation between exercise and cognition.

Human Cognition: The Model within which Physical Stress May Work

Human cognition is a complex set of processes. A detailed consideration of the entire array of functions is far beyond the scope of this review. Instead a general overview of cognition will be addressed and then a more detailed review of several significant functions, which will be measured in this study, will follow.

The model of human cognition includes several distinct types of memory, often conceptualized as discrete storage locations, processes for moving information into and between these various memories and a set of control functions that respond to and manage the information in our memory.

According to Baddley (2003), the central executive is the most important, but least understood component of working memory. The central executive mediates processing routines (e.g., encoding, storing, retrieving), by selecting, initiating, or terminating specific routines. According to Baddley (1992, 1997) the supervisory attentional system (SAS), first described by Norman & Shallice (1980), mirrors the central executive. The SAS is a limited capacity system involved for various purposes such as decision making and planning. SAS would be activated in scenarios such as difficult situations that are dangerous and complex, situations that are novel and notably, situations where strong habitual responses, impulsivity, or temptations are present (Shallice, 1982).

Attention, as managed by the central executive, is a set of cognitive processes that help us focus on certain information in our environment. In a crowd of people, several conversations overlap each other. This situation and the stimuli present are quite overwhelming. Yet, the central executive is managing attention, attending only to the conversation an individual is involved in and are only aware of the pertinent information, while filtering out the rest. This phenomenon is known as the “cocktail-party problem” or selective attention. Cherry (1953) tested this phenomenon by playing two different audio messages into different sides of headphones. One message would play in the left ear another message would play in the right ear and the participant was asked to repeat aloud what was being said in one ear. This is “shadowing” the attending ear. The participant is “unattending” to the message being played in the other ear. Participants could not recall what was being said in the message to their unattended ear. Further, participants could not even distinguish changes in gender, tone, and volume in the unattended ear. However, attention is not a complete filter. Depending on their relevance or importance, selective attention can pick out keywords and phrases that the central executive deems important, such as your name or provocative terms being said amongst an array of auditory confusion (Moray, 1959).

Yet, attention is limited. Attention cannot remain focused indefinitely. At some point attention begins to fatigue. It becomes much harder to concentrate on a given attentional task. During World War II, the British Navy was interested in attention fatigue in sailors monitoring sonar screens and periscopes for extended periods of time. Mackworth (1950) designed a task to test attention fatigue where subjects were told to stare at a clock face and report by pressing a button, when the second hand skipped two seconds with a jerking motion (targets). Mackworth found that the longer participants stared at the clock face, the more prone they were to miss the targets, where the second hand skipped two seconds.

Returning for a moment to the cognitive effects of physical stress, attention fatigue was even worse when the temperature of the room was above 83 and 87.5 degrees Fahrenheit (Mackworth, 1950).

Researchers also have tested attention fatigue with various types of image perceptions. When subjects are instructed to look at an ambiguous figure, they consistently report that the image repeatedly reverses from one figure to the other. The Necker cube, an optical illusion developed by Swiss crystallographer Louis Albert Necker, and other famous ambiguous images such as the old lady/young lady, vase/faces, and duck/rabbit have been used in studying attention fatigue. In the Reversible Figure Test (RFT) using either the Necker cube or one of the ambiguous figures, attention fatigue is scored as the number of times the image reverses. The more attention is fatigued, the more the image reverses (Halliday & Gordon, 2012; Macemore, Hurlbutt & Gordon, 2011; Shemery, McConnell, Halliday, & Gordon, 2012).

Automatic processes can be viewed as simple responses to the information that is constantly being received from the environment. People react to environmental stimuli without consciously making a response decision. Take for example, the odd sensation of been so distracted while driving that you were not paying attention to the traffic, yet you arrived at your destination safely. In this case some automatic processes made decisions without any conscious involvement. It is as if human-beings have their own internal auto-pilot.

The importance of automatic processes is especially important in response-inhibition. Response-inhibition is also known as impulse control. Behavior is managed with specific goals in mind. When the temptation to eat a slice of cake or the resistance in saying something inappropriate when a toe is stubbed on a piece of furniture in the middle of the night, response inhibition is at work. However, these cases probably involve some level of deliberate evaluation and conscious decision. Sometimes a person will act or refrain from action through a process that is completely outside their awareness. This is central executive control of response inhibition.

Stroop (1935) made a name for himself by introducing the Color-Word Interference Test, now known as the Stroop Task (ST). Stroop asked his participants to read a list of color-words printed in various colors. The directions were to identify the physical color of the word, not the color meaning of the word. For example, if the color of the word was “red,” but the word was “blue,” the participant would read the word as red. Stroop used five color words (e.g. red, blue, green, brown, and purple). Subjects were tested on their time of completion when they had to correct their errors on each trial. Stroop found that his interference test took participants 74% longer to identify the color of the ink when the physical color of the word was incongruent with the color meaning of the word. Stroop reported this as a “marked interference effect”.

Although Stroop is credited for the color-word interference task, Cattell studied the length of time required to read inconsistent word-color groups in 1886, 50 years before Stroop. While Stroop’s seminal article is more influential now than it was when it was received, Cattell’s research on automatic and voluntary distinction is an important starting point to response-inhibition that should not be overlooked.

The original Stroop Task has since taken various forms. There are empirical studies on variations of the Stroop Task such as variations in hues, pictures, acoustics, and semantics. One common difference between the original Color-Word Test and many contemporary versions is the use of congruent color-words among the list of incongruent color-words (e.g. the color-word red is in red ink). Although not used by Stroop, researchers have used congruent color-words interspersed with incongruent color-words. However, Langer & Rosenberg (1966) found the inclusion of these congruent items made no difference in overall response time. Whether the participant was reading all incongruent color-words or incongruent color-words with congruent color-words interspersed throughout the test, there was no significant change in the overall response time.

In a review of the Stroop effect, MacLeod (1991) reports that there is no sex differences in Stroop interference at any age.

Short-term memory (STM), or working memory, is part of human memory process that receives information and retains it briefly or allows us to encode the material for storage in long term memory. STM allows us to store information for only a short period of time, before it is either stored in our long-term memory, to be later recalled, or simply forgotten. The efficiency of this system differs, but generally shows marked capacity limits. Miller (1956) arrived at the “magical number seven plus or minus two” as the average adult’s working memory span for unrelated items.

Research on STM goes back to Ebbinghaus (1885) who looked at the basic processes of memory that are not dependant on previous memories or knowledge. Ebbinghaus studied his own memory using nonsense syllables (e.g. CUV, DAL, JUH). He would try to store and later recite the items as efficiently as possible. Ebbinghaus’s learning curve is consistent with Miller’s magical number data. Ebbinghaus found he could easily recall up to seven items, but syllables after seven took exponentially more viewings to recite perfectly. A major limitation to Ebbinghaus's research was that he was the sole participant; however, his work on memory has been a starting point for many later researchers.

STM capacity changes across our life. There is an increase in STM capacity in early childhood (Dempster, 1981) and later a decrease in old age (Kail & Salthouse, 1994). Of course, the information we do take into our STM does not stay there indefinitely. Brown (1958) and Peterson & Peterson (1959) studied the duration of information in our working memory. The Brown-Peterson task measures the length of time information stays in STM. This interval is roughly 18 seconds. If you were to be given a telephone number and then someone interrupted you with conversation, it would be challenging to recall the telephone number correctly after 18 seconds.

There are several ways to test STM. One common, valid, reliable measure is the Digit-Span task (DS). DS measures how many numbers a person can recall from STM. This test of STM presents random sequences of digits in increasing lengths. The sequence is recalled immediately after presentation. After each trial, the number of digits presented is increased. The maximum number of digits recalled is considered the person's digit span. Typically, DS is presented from three to nine digits. There are variations of this test, including the Reverse Digit-Span task (RDS). Similar to DS, the participant is required to recall the digits after presentation, but RDS requires that recall be in reverse order of presentation (e.g. 8, 2, 5 would be correctly recalled as 5, 2, 8).

The most obvious way to produce physical stress is through exercise. The stressful impact of physical exercise is apparent in cardiac function. Previous studies of exercise induced stress suggest that cardiovascular function, measured as heart rate, is a valid, reliable measure of stress. For example, high intensity exercise, defined by elevated cardiovascular function, can increase plasma cortisol levels (Moorthy & Zimmerman, 1978). There are several ways to calculate the appropriate heart rate reactivity for various levels of exercise stress. Several studies have used Vo_2 max to predict optimal heart rate (Gaesser & Rich, 1984; Gossard et al., 1986; Takeshima et al., 1993). Other researchers have used a change in beats per minutes, determining a fixed heart rate as the target goal for every participant (Faria, 1970; Sharkey & Holleman, 1967). In this study, the heart rate measure of moderate cardiovascular stress, will be the participants' individual percentage of maximal heart rate reserve (HRR). The HRR is an accurate estimate of an individual's cardiac capacity. This measure allows for various levels of individual fitness with a few simple calculations. Once HRR is calculated (see Calculations) for each participant, heart rate will be maintained between 45% and 55% of their HRR. 50% of HRR is a well established measure of moderate cardiovascular intensity or stress (Foster et al., 1989; Hooker, & Wells, 1989; Strath et al., 2000; Treasure, & Newbery, 1998).

Hypothesis

The Yerkes-Dodson law outlines a clear relationship between arousal and performance. If physical stress can function as a source of arousal, then it should be possible to relate stress and performance. Specifically, this study will measure whether cognition is positively or negatively affected by a mild to moderate cardiovascular stress. Cognition will be measured with three functions: directed attention, response inhibition and short-term memory.

This study predicts that moderate cardiovascular stress will produce a significant positive difference in attention, short term memory and response inhibition.

METHOD

Participants

Fifty-five undergraduate students or similar volunteers were used in the study. The students participated to partially fulfill a course requirement. Twenty-eight of the participants were tested in a sedentary control condition and twenty-seven were in the moderate cardiovascular stress condition. These two conditions are described below. All of the participants in the moderate cardiovascular stress condition were screened under two exclusionary rules. An individual for whom moderate cardiovascular stress would present a significant health risk was to be excluded from the study. If an individual was not excluded based on screening question, but then showed an extreme response during the walking pre-test, either too much or too little change in heart rate, that individual was to be to be removed from the experiment. No participant in the moderate cardiovascular stress condition was excluded based on these rules.

Calculations

The Target Heart Rate (THR) of between 45% (minimum) and 55% (max) of Heart Rate Reserve (HRR) was calculated using the following formula:

$$HR_{max} = 220 - Age$$

$$HRR = HR_{max} - HR_{resting}$$

$$THR_{minimum} = (HRR \times .45) + HR_{resting}$$

$$THR_{max} = (HRR \times .55) + HR_{resting}$$

Materials and Measures

A consent form (see Appendix A) and a demographic form (see Appendix B) were given to each participant.

The cognitive tests used three different measures. The reversible figure test (RFT) is an attention measure. The RFT is a 60s presentation of the Duck-Rabbit reversible figure (see Appendix C). During the 60s presentation, the participant touches the iPad screen each time the figure seems to change its appearance.

The reverse digit span test (RDS) is a short term memory measure. The RDS presents a series of 3 to 9 digit sequences which the participant has to recall in reverse order. The digit presentations increase in duration as the number of digits increases. Each sequence was presented as successive single digits. Each digit was presented boldfaced and featured in a black Garamond font against a white field. Each digit appeared for three seconds and then transitioned to a white blank screen for two seconds. Participants viewed each sequence and then recalled the sequence in reverse order (e.g. 2, 5, 3 is correctly answered as 3, 5, 2). The longest digit span correctly recalled is the participants' digit span. The test-retest reliability of the RDS is a 0.66 to 0.89 correlation (Lezak, 2004).

The Stroop test (ST) is a measure of response inhibition. The ST presents participants with a list of color-words. In congruent trials the physical color and color meaning match. For incongruent trials the physical color and color meaning are mismatched. Participants were expected to report the physical color of each word by tapping the appropriate field on the iPad. Participants were not able to proceed until the correct answer was reported. The ST had twenty items using five different color-words: red, blue, green, brown, and purple. Ten color-words were congruent and ten were incongruent. Each color-word combination was used twice, but never directly following each other. Each color-word appeared equally often in each of the four ink colors.

According to Schubo & Hentschel (1977, 1978), Smith & Nyman (1974) and Uechi (1972) the ST has high reliability. Siegrist (1995) acknowledges the lack of estimations of reliability for most of the versions of the Stroop tests in the literature. Seigrist ran his own ST and found response latencies and Stroop interference was quite reliable ($r=.87$, $p<.001$). His single stimulus presentation allowed for a high estimate of internal consistency for the classical Stroop interference.

In the RDS and ST the presentation order for the individual test items were randomized within the measure. The entire test lasted for roughly forty-eight min. During the test, the sedentary control (SC) group watched three video segments; each six min in length. These videos were pilot tested to establish that they did not fatigue attention. The videos featured a magician performing illusions.

During the moderate cardiovascular stress condition (MCS), the participants walked on treadmills (PrecorUSA c956i; LifeFitness 9100). The participants in the MCS condition wore chest strapped heart-rate monitors

(POLAR T31-CODED). The cognitive function tests and video clips were presented on iPad 2 tablet computers.

Procedure

At the start of the experiment, participants were asked to read and sign a consent form to participate (see Appendix A). Demographic information was taken after the consent form was signed. The demographic information was reviewed as an exclusionary test. Participants were to be excluded from the experiment as described above. No participant met the requirements of exclusion.

MCS participants were tested in a semi-private fitness facility with two researchers present on days with more than three participants. On days where three or fewer participants signed up, there was only one experimenter present. The fitness facility was a large area with two rows of treadmill machines, next to an array of exercise equipment sitting on a thinly cushioned carpet. In the sedentary condition (SC), the participants were tested in a standard classroom at individual desks with one researcher present. The MCS participants were tested two to six at a time with two researchers present when a group of four or more were present. The SC group was tested in groups of eight to ten participants.

In the moderate cardiovascular stress condition (MCS), the participants were given their chest mounted heart rate monitor to be worn before the cardiac function pre-test. Once participants had their heart rate monitors properly fastened, they were instructed to return to a sitting position and relax, so that their resting heart rate could be measured. There is a typical pattern of heart rate recovery. After one minute of rest, participants will show an abrupt decline in heart rate. After two minutes, participants' heart rate will start a gradual decline, known as heart rate recovery. From that point on heart rate will level out into what is known as a resting plateau. It may take an hour for participants to reach complete resting or baseline heart rate after exercise that brings their heart rate to sub maximal levels (Nishime, et al., 2000). However, since the MCS participants had not been under high cardiovascular demand before arriving at the test facility, there was no delay in determining each participant's resting or baseline heart rate. The measure after five minutes of rest was taken as Resting Heart Rate (RHR). Once RHR was determined the experimenters calculated the target heart rate minimum and maximum for each participant.

Heart rate was not measured in the SC group, because participants were in a seated position for the entire procedure. Heart rate monitors were to only be used to help identify the heart under higher levels of stress and maintain that level. The SC group were in a resting state during their procedure and heart rate monitors were not necessary in establishing heart rate a low level of arousal or resting heart rate.

The MCS participants were assigned a treadmill and they completed the cognitive measures three times while walking on the treadmill. MCS participants were encouraged to drink small amounts of water throughout the procedure, to reduce the possibility of dehydration. Dehydration is detrimental to cognitive function (Lieberman, et al., 2005; Tomporowski, 2003). Regular commercial bottled water was available to each participant at the start of the experiment. A few participants brought their own bottles of water with them to the experiment and they were allowed to drink their own water.

All of the MCS participants were evaluated with a cardiac function pre-test before beginning the test. Each participant was monitored on a treadmill test of cardiac reactivity. The treadmill test had the participants increasing in speed every 30 s, by one mile per hour (mph) until the participant's heart rate was between 45% and 55% of that participant's heart rate reserve. The speed then remained constant for 30 s to see whether the participant remained at that level of cardiac function.

If the participant showed an atypically large cardiac reactivity, a change up to or more than 60% of their HRR, for more than five minutes, the pre-test was to be terminated and that participant would be excused from the study. If a volunteer shows an atypically small change in cardiac reactivity, down to or less than 40% of their heart rate reserve, for more than five minutes, the participant would be excluded from the study. No participant failed the cardiac function pre-test and all were able to proceed through the rest of the experiment.

The pre-test determined the speed necessary to increase the participants' heart rates to the target range, between 45% and 55% of their HRR. During the actual MCS test, the participant's heart rate was maintained in the target range by increasing or decreasing the speed of the treadmill. Thus, each participant was tested at the same level of physical stress, but at various levels of treadmill speed. After the participants maintained their HR in the target range for one minute, their HR was noted and they were instructed to begin the test.

All participants completed the cognitive measures three times. Between the three measurements, the SC participants watched three 6 minute video clips (described above) presented on an iPad tablet computer. After each six minute video clip, SC participants completed each cognitive measure using the same iPad tablet. Once the test began for the MCS condition, the participants walked on treadmills continuously for roughly forty-eight minutes.

In both conditions, there were three cognitive test blocks. Each cognitive test block included three tests: RFT, RDS and ST. The order of the three tests was randomized within each of the three test blocks.

Once cardiac function pre-test was complete and the participant's heart rate was stable in the target range, the MCS group started their test. During all intervals a timer presented on the iPad indicated the time left until the next test. The MCS group continued walking during all of the test trials. Participants were given the freedom to stop during the procedure at any time for any reason. In between test blocks the MCS participants rated their level of perceived exertion (RPE) according to the scale developed by Borg (1982). The rating scale, often referred to as the "BORG (RPE) scale" asks a physically active participants to rate his or her perceived level of exertion from 6, no exertion at all, to 20, maximal exertion. Researchers were instructed to stop a participant who indicated a 17, exercise is very hard (very strenuous, and you are very fatigued), or higher. During the procedure, no participant indicated a rating of perceived exertion higher than 12.

After the final test block, the experiment was complete for the MCS group. They were instructed to slow down to a complete stop and then instructed to remove and return all HR devices attached to their person. Once the equipment had been collected the researchers offered to answer any questions and confirmed that the MCS participants felt fully recovered. The participant was then thanked and dismissed. The SC group watched their third and final six min clip after the final test trial. Once the video clip was finished the researchers offered to answer any questions. The SC group was then thanked for their participation and dismissed.

RESULTS

For this experiment one independent variable (IV) was the stress condition: moderate cardiovascular stress condition (MCS) and the sedentary condition (SC). This between-subject design had participants experiencing only one of these conditions. The second IV was time. This was a repeated measures design and participants were tested three times.

There were three dependent variables (DVs) testing various aspects of cognitive function. The Reversible Figure Test (RFT) has ratio values between zero and infinity. The RFT is the number of reported reversals during a 60 s period observing the Duck-Rabbit figure. An increase in the number of reported reversals is an indication that direct attention is not operating as effectively.

The Stroop Task (ST; Stroop, 1935) has interval values between a negative time (-##:##) and a positive time (+##:##). Stroop scores are the difference in the total time it took the participant to complete the 10 congruent color-word trials and the time it took the participant to complete the 10 incongruent color-word trial. This would be represented as: Σ reaction $\text{times}_{\text{congruent trials}}$ - Σ reaction $\text{times}_{\text{incongruent trials}}$. Values closer to zero represent increased response inhibition which is a weak Stroop effect. Greater negative values represent decreased response inhibition which reveals a stronger Stroop effect. If the participant is actively inhibiting naming the word then there would less of a delay on incongruent trials. If the word naming response remains active then the participant has to overcome that tendency and then name the color.

This would slow the reaction and increase the reaction times on incongruent trials. Thus, a negative ST scores indicates less inhibition. Positive ST values reveal participants performing better on the incongruent color-word trials than the congruent word-trials. There is no cognitive basis for superior performance on incongruent trials so positive ST values reveal an error in the test.

The reverse digit span test (RDS) can have a value of zero, no digit span was correctly recalled, or values between three and nine, equal to the longest digit sequence recalled correctly in reverse order.

Fifty-seven participants completed the three test blocks. Twenty-eight participants were in the sedentary condition, and twenty-seven participants were in the moderate cardiovascular stress condition. Appendix D lists the average scores, with standard deviations for the three DVs in each condition. Appendix E lists the recorded heart rates of each participant in the MCS condition over the course of the procedure.

A repeated-measures analysis of variance (rmANOVA) was conducted for each DV. An eta squared (η^2) was calculated for a measure of an effect size with 0.10 being a small effect size, 0.25 being a moderate effect size, and 0.40 being a large effect size. No post-hoc test were required due to all possible pairwise conclusions being met for the two conditions present. As predicted in the hypothesis, there was a main effect of stress on direct attention. The MCS condition showed significantly fewer figure reversals than the SC condition on the RFT measure, with a large practical effect (SC $\bar{x}$ = 20.476, MCS $\bar{x}$ = 19.747, $F(1,55)=72.393$; $p<.001$, $\eta^2 = .568$; See Appendix F). There was no significant main effect of time ($F(1,55)=1.545$; $p=0.218$). There was no significant interaction ($F(1,55)=0.010$; $p=0.990$).

Contrary to the hypothesis, the main effect of stress was to reduce short term memory. The RDS was significantly larger in the SC condition than the MCS condition, with a large practical effect (SC $\bar{x} = 6.813$, MCS $\bar{x} = 6.381$, $F(1,55)=1590.405$; $p<.001$, $\eta^2 =.969$; See Appendix G). There was no significant main effect of time ($F(1,55)=0.389$; $p=0.679$). There was no significant interaction ($F(1,55)=1.863$; $p=0.160$).

There was no main effect of stress on response inhibition. The ST scores in the SC or MCS conditions were not different (SC $\bar{x} = -0.543$, MCS $\bar{x} = 2.019$, $F(1,55)=.426$; $p>.05$; See Appendix H). The data from the ST was then broken down to analyze the congruent color-word trials and the incongruent color-word trials separately. Analysis found a significant difference between the SC and MCS conditions for the total reaction time in the congruent trials (SC $_{\text{Congruent}}\,\bar{x} = 31.576$, MCS $_{\text{Congruent}}\,\bar{x} = 57.575$, $F(1,55)=859.182$; $p<.001$, $\eta^2 = 0.940$; See Appendix I) and the incongruent trials (SC $_{\text{Incongruent}}\,\bar{x} = 32.119$, MCS $_{\text{Incongruent}}\,\bar{x} = 55.556$, $F(1,55)=784.757$; $p<.001$, $\eta^2 = 0.935$; See Appendix J). Both the congruent and incongruent trials had a large practical effect. The quicker responses on both congruent and incongruent color-word items in the SC condition versus the MCS condition reveals the procedural error in the ST. This error will be explained below.

DISCUSSION

This experiment was designed to test the effects of moderate cardiovascular stress on three aspects of cognition. The relationship between cognition and physical stress varied across the three cognitive measures. Attention, measured with the RFT, was restorative across the three test blocks but the participants who were under cardiovascular stress were significantly more restored.

Short-term memory, measured with the RDS, was reduced when the participants were under cardiovascular stress. It may seem odd that attention and short-term memory don't covary. However, in most models of cognition attention is a separate process that precedes encoding for storage in memory and operates independent of maintenance rehearsal for retention in short term memory. Thus attention may improve while encoding, storage and maintenance falter. The ability to focus on a given task does not necessarily predict superior short term memory performance.

While the Stroop Color-Word Task revealed a significant difference between the SC and the MCS groups this does not accurately reflect the MCS groups true score on the Stroop Color-Word Task. Responding in the ST on the iPad was reliable for the SC group because they were seated at a desk and could easily and consistently tap the submit button on each trial. The MCS group were moving and could not easily tap the submit button. MCS participants had difficulty tapping the submit button directly after answering each item. Multiple taps were required to advance to the next item. These additional responses added extra time during both congruent and incongruent trials. The differences between the response times in the SC and MCS did show a significant difference, but the difference was probably not due to the stress condition. The difference seen in the ST was due to procedural error. This error can be corrected with a more effective response device that captures less well controlled responses.

Thus these results are split in confirming the hypotheses stated above. Attention was restored in both the SC and MCS conditions, but moderate cardiovascular stress has a beneficial effect of restoring direct attention. Participants in the MCS condition experienced considerably more attention restoration than those in the SC condition. Most people have heard someone describe their ability to think well during or after exercise. These data are consistent with those observations.

While under moderate physical demand, people are able to attend better and possess a sense of clarity. These results have great potential implications to how we approach education or the workforce. In an educational environment, in specific, students are required to sit at a desk and attend to materials over long durations of time. Understanding that moderate physical demand is restorative to attention could improve the ability to focus in such a situation. Since these results reveal the restorative effects of people exercising versus those in a low state of arousal, it can be assumed that implementing times during the day to which someone can be active would translate to higher levels of attention and the possibility of performance thereof.

However, there is a counter finding. Yes, exercise may protect attention but it does not appear to help short-term memory. There are a couple of possible explanations of this finding. First, it can be taken at face value. Exercising has a negative impact on short term memory. A viable alternative may be that exercise reduces that participant's ability or opportunity to maintain the contents of short term memory. In the classic work demonstrating loss of short term memory Peterson and Peterson (1959) showed that when maintenance rehearsal is blocked, memory loss increases. If walking interferes with maintenance rehearsal that could account for the negative effect.

These findings are in no means disparaging towards the concept that 'exercise' has a negative impact on memory, but that 'exercising' is more or less interfering with maintenance rehearsal, which is depreciating our ability to store, encode, and recall memory. Since this research only measured cognitive performance while people exercising or not, it can only be said that performing optimally on a cognitive task that demands our short-term memory, would be best approached while in a relaxed state.

Future Research

This research looked at two points on the relationship between performance and arousal. The SC condition showed the performance level at a low level of cardiovascular stress. The MCS condition showed performance at a moderate level of cardiovascular stress. What is left to be explored is the relationship between high levels of cardiovascular stress and performance on cognition. Norling, Sibthorp, Suchy, Hannon, and Ruddell (2010) tested the recovery from attention fatigue on recreational runners at four varying degrees of physical intensity: self-regulated, low, high and a resting control group. They found that at higher intensities of physical exercise, people recover from attention fatigue better. This concept could adequately support the idea that at higher levels of arousal, like stress produced through cardiovascular exercise, could be beneficial to other aspects of cognition. With measures that can accommodate the physical motion of runners on a treadmill, a third point on the relationship between performance and arousal could be better understood.

Another cognitive measure of memory could be used to replicate this findings. A preferred approach were to find a measure of memory that does not demand the participant to utilize maintenance rehearsal, since participants need to be active in some manner.

Unfortunately, a true score of response inhibition could not be attained from the MCS condition due to the precision required in pressing the advance button in a timely fashion. If a revision were to be done to the ST where a participant was able to press a submit button of a greater size or even a feature where after a correct response the question would automatically submit and advance to the next item, a more accurate measure of response inhibition could be reached. A consistent medium for taking each test (i.e. an iPad) was appropriate and necessary for the conditions at play during the time of this research. However, each measure being available on one device or medium is not necessarily essential. It could be done with different forms and devices, but considering the number of experimenters needing to be present for this to be effective was not possible given personal constraints.

Conclusion

While this research does not advocate stress as a strategy for optimizing cognitive performance, the broader benefits of an active lifestyle would certainly outweigh the minor short term decrements in short-term memory. If such decrements actually exist. An active lifestyle that exposes individuals to moderate cardiovascular stress has many worthwhile physiological effects and, according to this research, protects direct attention. This protective effect may be linked to the mental clarity that is associated with exercise.

Yet, this research only looks at two levels on cardiovascular intensity and can only paint part of the picture. While it will be more challenging to measure cognitive function during high intensity cardiovascular stress the question is worth asking and that test could produce some interesting changes in cognition. For example, if the negative effect on short term memory is due to less effective maintenance rehearsal then this effect should increase under high intensity exercise. If short term memory were to improve under higher levels of cardiovascular stress that would rule out this confound.

Future research will hopefully identify the mechanisms at work under various levels of physical stress. With an alteration to procedural constraints to capture an accurate measure of response inhibition, we could acceptably see an improvement in response inhibition for those under physical stress. Another measure of short-term memory could also be assessed to replicate or add new information to these findings.

Continued research on physical stress and cognition could substantially change the way we approach work, education, and even simply day-to-day life. Knowing that physical exercise impacts our ability to attend, store information, and recall that information could improve job performance in the workplace. It could better facilitate learning in education and help us transition from an exhaustive day into a fulfilling evening with the one's we care about. Being aware of how our cognition is shaped by the level of physical demand we put ourselves under could be invaluable towards our attainment of a life that is both prosperous and fulfilling.

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APPENDIX A: INFORMED CONSENT

Western Carolina University

Department of Psychology

Here are some questions you might have about this study.

What is the purpose of this research? We are conducting research to better understand the effect of moderate intensity exercise on cognitive performance of the Stroop color-word interference task, Reversible Figure Attention task, and a Reverse Digit Span test. We will be conducting moderate bouts of exercise during which you will be asked to take these three measures of cognitive performance through an internet hosted survey via an iPad.

What will be expected of me? Your involvement in this project involves wearing a heart-monitor while operating a treadmill at a fast paced walk/jog for roughly an hour. During your exercise on the treadmill, you will be asked to complete a test battery five times with intermittent periods of continued exercise.

How long will the research take? Approximately 1 hour and 30 minutes.

Will my answers be anonymous? Your responses will be held strictly confidential. You will not sign your name to the survey at all.

Can I withdraw from the study if I decide to? Your participation is voluntary. You may withdraw at any time or decline to answer any question you choose.

Is there any harm that I might experience from taking part in the study? There are no more than minimal risks to be expected from taking part in this study. You will be exercising on a treadmill for roughly an hour. Physical fatigue and muscle soreness is to be expected.

How will I benefit from taking part in the research? You will be satisfying a requirement to participate in research if you are a PSY 150 student and/or receiving extra credit if you are a PSY 271 student. In addition, you will get the satisfaction of knowing that you are participating in research that will give new understanding to how moderate physiological stress affects the way we think.

Who should I contact if I have questions or concerns about the research? If you have any concerns about how you were treated during the experiment, you may contact the office of the IRB, a committee that oversees the ethical dimensions of the research process. The IRB office can be contacted at 227-3177. This research project has been *approved** by the IRB.

I am interested in the results of this experiment. How can I receive this information? If you decide you want a copy of the results, you may elect to receive them via email once they are complete. Please notify your email address below for an email of the results.

____

Records of email addresses will only be kept temporarily until sent electronically to your email address. Once sent, all emails will be erased.

Please sign your name below if your consent to participate in this research.

____

Signature

Thank you for participating in our research.

Michael McGathy

APPENDIX B: DEMOGRAPHIC INFORMATION

Participant Number:

____

Sex (Circle one):

MALE FEMALE

Birthdate:

____

How often do you engage in physical activity that increases and maintains a much higher heart rate (Circle one)?

(1 = Rarely, 3 = Sometimes, 5 = Frequently)

1 2 3 4 5

Do you smoke (Circle one)?

YES NO

If you answered yes, to the above question, how often do you smoke per week? (Circle the one that best fits your habits)

(1 = Rarely, 3 = Sometimes, 5 = Frequently)

1 2 3 4 5

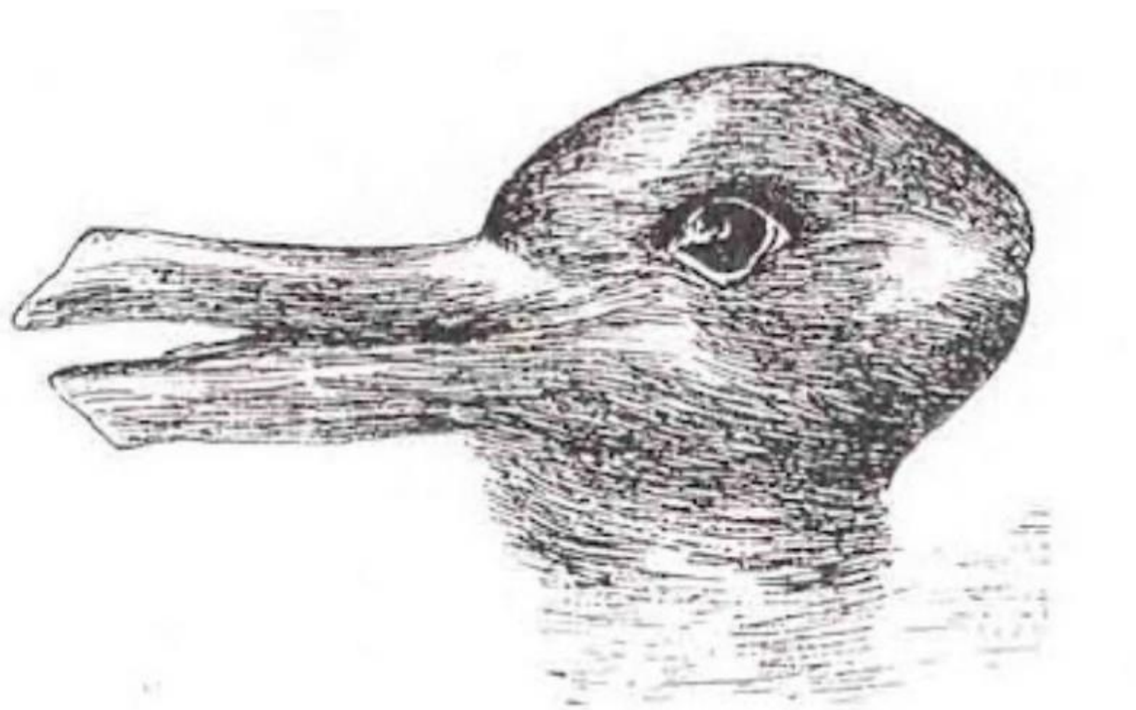
Resting Heart Rate

____

Target Heart Rate

Min_____________ Max_____________

APPENDIX C: THE DUCK-RABBIT IMAGE FOR THE RFT



APPENDIX D: DESCRIPTIVE STATISTICS FOR EACH DV IN BOTH CONDITIONS

Descriptive Statistics

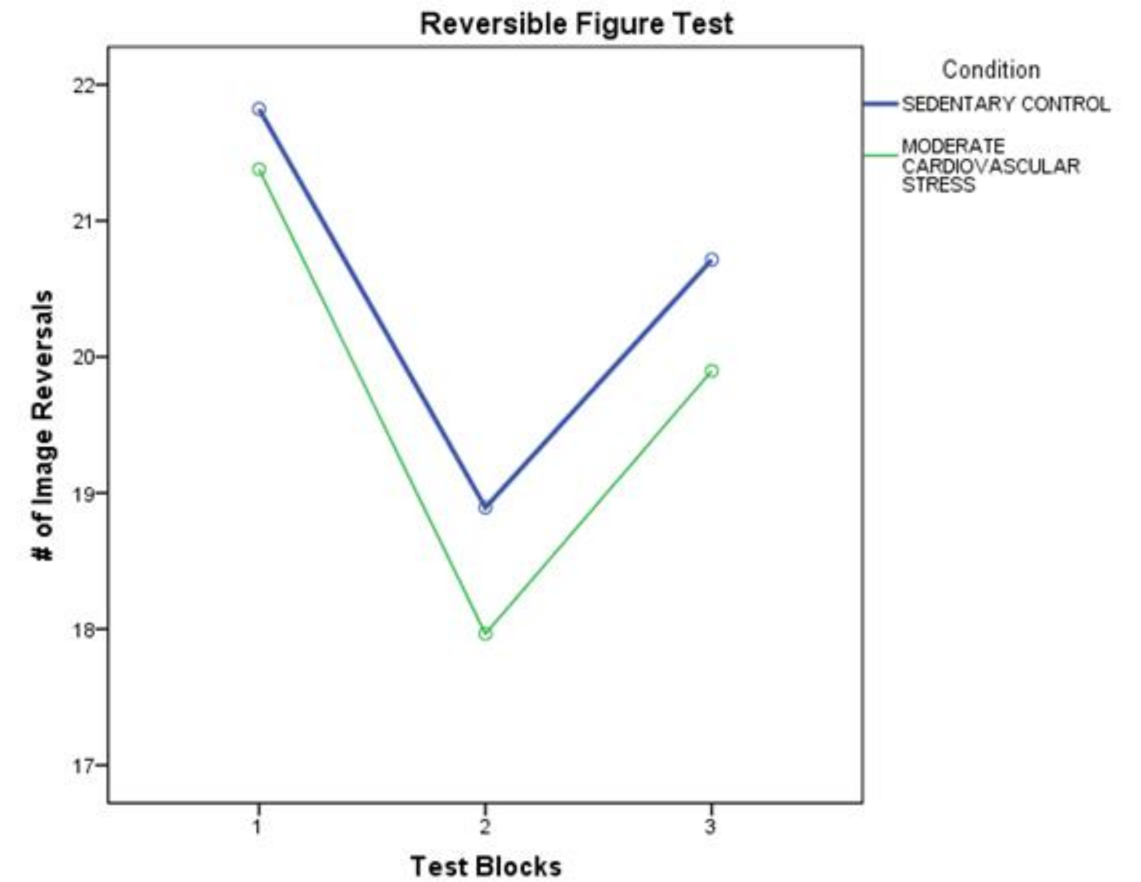
DV	Condition	Mean	Std. Deviation	N
RFT1	SC	21.82	17.845	28
	MCS	21.38	24.383	29
	Total	21.60	21.233	57
RFT2	SC	18.89	12.612	28
	MCS	17.97	22.560	29
	Total	18.42	18.204	57
RFT3	SC	20.71	17.524	28
	MCS	19.90	19.607	29
	Total	20.30	18.452	57
ST1	SC	-2.4955	8.06413	28
	MCS	2.4758	10.44509	29
	Total	.0338	9.60159	57
ST2	SC	-.5431	7.72330	28
	MCS	1.8542	17.92526	29
	Total	.6766	13.81590	57
ST3	SC	1.4103	8.95922	28
	MCS	1.7264	15.65296	29
	Total	1.5711	12.69777	57
RDS1	SC	6.56	1.557	25
	MCS	6.39	1.524	28
	Total	6.47	1.527	53
RDS2	SC	7.12	1.590	25
	MCS	6.14	1.580	28
	Total	6.60	1.645	53
RDS3	SC	6.76	1.363	25
	MCS	6.61	1.812	28
	Total	6.68	1.603	53

SC= Sedentary Control
MCS = Moderate Cardiovascular Stress
RFT = Reversible Figure Test
ST = Stroop Test
RDS = Reverse Digit Span

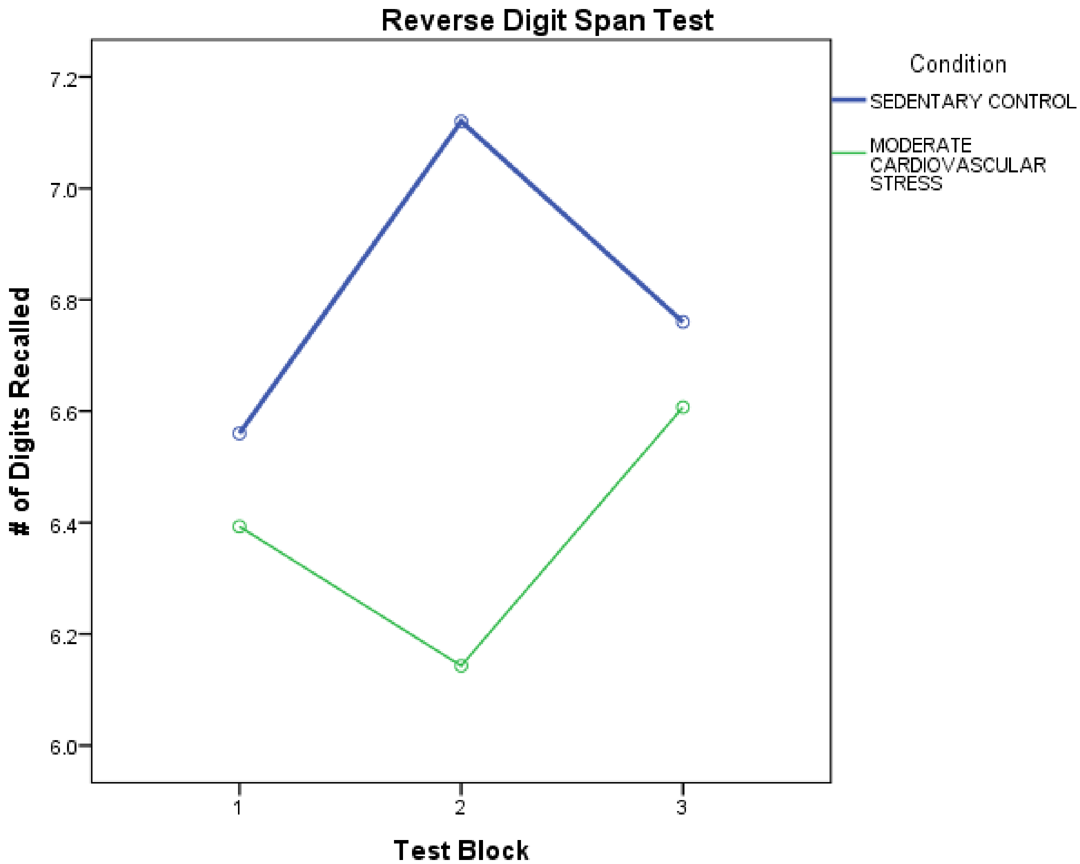
APPENDIX E: HEART RATE FOR PARTICIPANTS IN THE MCS CONDITION

	Heart Rates for MCS Participants					
	Test Block 1	6min1	Test Block 2	6min2	Test Block 3	End
Participants	137	139	133	142	141	141
	139	133	135	138	138	132
	140	133	132	122	136	140
	134	126	131	135	133	131
	157	155	154	158	155	156
	146	160	146	148	146	148
	140	146	141	142	137	140
	144	155	148	145	148	142
	138	131	143	143	143	155
	131	132	133	131	135	136
	134	134	138	138	140	129
	132	140	134	131	137	130
	135	139	138	138	144	139
	133	150	134	136	142	135
	142	141	142	135	141	141
	136	126	133	140	138	149
	139	136	135	154	148	155
	148	138	148	142	146	147
	144	142	136	137	131	118
	145	141	142	144	141	140
	150	149	154	153	152	154
	140	139	143	139	147	146
	148	150	153	144	145	151
	146	146	146	156	137	143
	136	135	137	134	136	109
	136	128	135	127	136	135
	153	149	150	155	152	151
	143	140	141	140	143	140
	139	136	140	136	136	139
Average HR	140.8620	140.3103	140.5172	140.7931	141.5172	140.4137

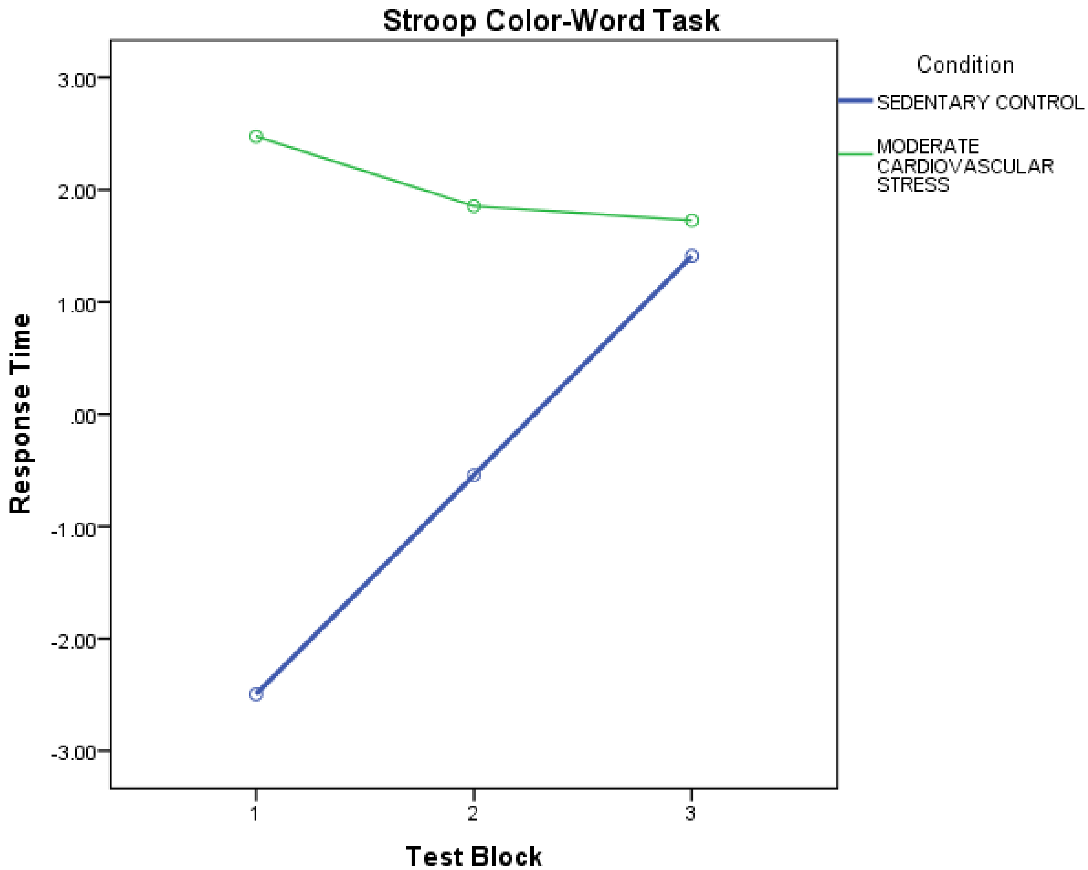
APPENDIX F: REVERSIBLE FIGURE TEST



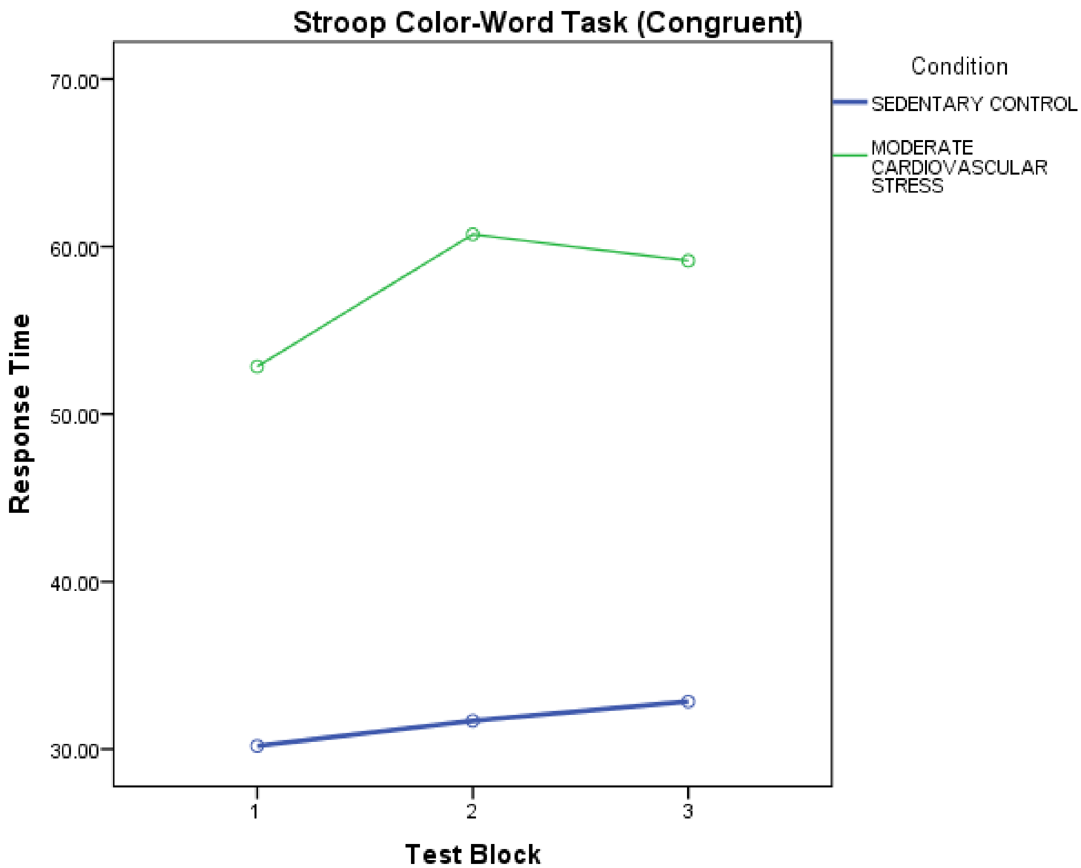
APPENDIX G: REVERSE DIGIT SPAN TEST



APPENDIX H: STROOP COLOR-WORD TASK (DIFFERENCES)



APPENDIX I: STROOP COLOR-WORD TASK (CONGRUENT WORDS)



APPENDIX J: STROOP COLOR-WORD TASK (INCONGRUENT WORDS)