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Effects of Mild to Moderate Stress on Mental Rotation

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Walden University
2015

Abstract

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by

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MA, University of North Florida, 2002

BA, University of North Florida, 1997

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Abstract

Mental rotation (MR) is the ability to mentally shift one's visual perspective of any object by changing the orientation of a mental image of that object. Research into the effects of stress on MR could be used to help improve understanding of a variety of visual-spatial tasks performed in hyper-vigilance situations. However, until the present study, there has been no research on the effects of stress on MR. The Yerkes-Dodson Law predicts performance will be improved when an individual is exposed to mild to moderate stress. The purpose of this study was to answer three research questions. The questions examined whether stress affects MR performance; if MR performance is improved by stress, impaired, or unchanged; and, if the effect of stress is related to the degree of MR task difficulty. Twenty healthy adult participants, aged 18 to 65, were recruited from the Savannah, Georgia area. The participants were divided into 2 groups of 10: stress and no-stress groups. The stress group was exposed to a math task under time pressure. The no-stress group was given a simple counting task to do at their own pace. Heart rate during testing was measured for both groups. “L-shaped” objects of varying angular orientation were presented on a computer screen immediately following the counting tasks. Participants choose whether the pair of objects were different mirror images of the other, or the same object, only rotated differently. A 2 x2 mixed repeated measures ANOVA indicated significant differences in heart rate between groups following exposure to the counting tasks. A 2-sample t test showed no significant differences between groups for MR performance. Social change implications include more efficient use of employee training in mild- to moderately- stressful jobs that require MR skills.

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Dedication

I dedicate my dissertation to my mother, Suzanne C. Cook, and my sister, Maryanne McKnight, both of whom passed away before they could see me complete my doctoral studies. I also dedicate this work to my fellow air crewmen of the United States Navy, and all other armed service members, who lost their lives in the line of duty.

Acknowledgments

I would like to thank my committee members for their support. I would especially like to thank Dr. Thomas Edman, my committee chair and class professor, for his guidance and encouragement during some of the most difficult times. I would also like to thank Walden University for encouraging doctoral students to find effective ways to conduct controlled experiments when a traditional laboratory may not be available.

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Chapter 1: Introduction to the Study

Background of the Study

Mental rotation (MR) is the mental manipulation of information held within visual-spatial memory (VSM) about an axis of rotation. More specifically, MR can be described as the ability to mentally shift one's visual perspective of any object by changing the orientation of a mental image of that object (Cohen & Blair, 1998; Wendt & Risberg, 1994). Shepherd and Metzler (1971) described mental rotation as an analogue process by which mental images are consciously moved along varying axes of rotation imagined by the observer. The brain performs MR without the need for the real-world target object (the object actually perceived by the eyes) to physically move or be physically moved or turned about. Rather, mental rotation is the *imagined* shift of visual perspective, by either imagining the movement of the object itself, or imagining the shifting of the observer relative to the object’s position, revealing sides of the object unseen by the observer when both the object and observer are stationary.

Mental rotation is a subcomponent of VSP, the set of visual processes that give us the experience of not only seeing our environment, but also understanding the relative positions, orientations, and spatial relationships of objects within that environment. Two main data forms: visual-object (the *what*), and visual-spatial (the *where*), are stored in VSM, where they can be acted upon by the process of MR (Cohen & Blair, 1998; Wendt & Risberg, 1994). Processed together, VSM and MR allow individuals to understand the dimensions, relative distances between, and spatial coordinates of elements comprising any visual scene.

Mental rotation has been and continues to be essential for a wide variety of functions, from common activities, such as finding one's way home from the market, or putting together a jigsaw puzzle, to highly complex tasks, such as landing an airplane at a busy airport (Deyzac, Logie, & Denis, 2006; Dror, Kosslyn, & Waag, 1993; Hund & Minarik, 2006; Gibb, Schvaneveldt, & Gray, 2008; Millivojevic, Hamm, & Corballis, 2011). Some tasks, such as flying an aircraft inside crowded airspace, place high demands on visual-spatial processing, and potentially induce high stress. Such tasks require the pilot to interact and maintain visual contact with one or more aircraft, at high speeds and under heightened physical and mental arousal, requiring rapid mental manipulation of both 2-dimensional cockpit information displays, and the real-world 3-dimensional environment surrounding the aircraft (Gibb, Schvaneveldt, & Gray, 2008; Gordon & Leighty, 1988; Leifflen et al., 1997).

In this experiment, I examined the effect of mild to moderate stress in the form of artificially elevated cognitive load on MR in normal adults. The experimental group received exposure to a cognitive load stressor in the form of a counting task under time pressure (independent variable). The control group was not exposed to the stressor. Both groups performed a MR task (dependent variable) displayed on a computer screen.

The results of this study will help inform human factors researchers, cognitive science, and the aviation industry on the relationship of stress and mental rotation performance. Knowledge gained from this study could lead to improved human-computer interfaces and displays for pilots, aircrew, and airtraffic controllers. Cognitive science would gain insight into how stress interacts with visual-spatial processes, and affects how we see and react to our world. Employers would gain better understanding of visual-spatial skills needed to effectively perform highly visual tasks under stress, which could result in the development of stress management and other related supports for such employees, thus resulting in positive social change.

In this chapter, I introduce the phenomenon of mental rotation (MR) as it relates to visual-spatial processing (VSP) and illustrate examples of its essential role in a wide variety of visual tasks. I then outline relative gaps in the literature regarding what impacts cognitive stress in the form of cognitive load may have on MR performance. The rationale for conducting this study, as well as the study's purpose and nature, are discussed. Critical terms used in this study are defined, and the limitations, delimitation, and significance of this study are detailed. Finally, assumptions made in this study are explained, and a summary of this chapter is provided.

Problem Statement

Mental rotation is of particular importance when engaging in complex visual-spatially demanding tasks, which could include driving a car, train, performing airtraffic control, or flying an airplane (Gordon & Leighty, 1988; Leifflen et al., 1997; Shepard, & Metzler, 1988; Van Orden & Broyles, 2000). Research into the effects of stress on such an important cognitive process as MR could be used to help select the best pilot and air traffic controller candidates, enhance human interfaces with avionic display technology, and help maximize performance.

Cognitive stress is one of many varieties of stress. Cognitive stress includes cognitively demanding tasks, which generally require greater use of cognitive resources, such as attentional proccesses, memory encoding and retrieval, decision making, etc. (Fitousi & Wenger, 2011). High demand on such resources increases cognitive load (Fitousi & Wenger, 2011), thus producing cognitive stress. While it is widely known that stress can affect performance on a huge variety of tasks, including visual-spatial processes such as VSM (Newcomer et al., 1999; Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric, & Davidson, 2006), it is not known what effect, if any, exposure to high cognitive load has on the cognitive process of MR.

Purpose of the Study

This was a quantitative study designed to experimentally examine the relationship of mild to moderate cognitive stress in the form of cognitive load on the MR of 3-dimensional objects presented in 2-dimensional space. The nature and presentation of such objects was intended to simulate the MR used in a variety of vehicles, such as aircraft, cars, trains, etc., where accurate ascertaining of object orientation to the viewer is essential for safe and effective performance. The independent variable was cognitive stress. The dependent variables were MR task performance (percent correct), and response time.

Theoretical Foundation

The Yerkes & Dodson Law (YD Law), Arousal Theory, Maximal Adaptability Theory, and Composite Theory are examples of theories of stress and performance which provide the theoretical foundation for the present study. The YD Law predicts that both very low and very high levels of stress impair performance, whereas mild to moderate levels of stress improve performance for a variety of tasks (Yerkes & Dodson, 1908).

Arousal Theory goes further and predicts that performance vulnerability to stress is a function of task difficulty; that is, higher stress can be more tolerated for easier tasks, compared to more difficult tasks where even small amounts of stress can impair performance (Broadbent, 1978; Luciano, Leisser, Wright, & Martin, 2004). Maximal Adaptability Theory predicts that an individual's performance will decrease as more and more stressors are combined (Szalma & Hancock, 2011). Composite Theory states that stressors such as noise affect inner speech (e.g., the silent solving of a math problem in one's mind), and thus decrease performance (Szalma & Hancock, 2011).

Nature of the Study

In this experiment, I attempted to determine the relationship of cognitive stress to MR. Two groups of adult participants with no reported physical or mental impairments performed a MR task. The experimental group was exposed to an additional counting task under time pressure, designed to induce mild to moderate levels of stress consistent with similar studies of stress and cognitive load (Camos & Barrouillet, 2004; Ingram, van Donkelaar, Cole, Vercher, Gauthier, & Miall, 2000; Lagman, 2000; Reisberg, 1983). The control group was not exposed to the stressor, but did perform the same MR task. A basic physiological correlate of stress, participant heart rate, was monitored in both conditions.

Research Questions and Hypotheses

The research questions that I addressed in this study were:

1. Are there differences in MR task performance between the stress and the no-stress groups?
2. If yes, is MR performance improved by the stressor, impaired, or unchanged?

3. Is the effect of stress related to the degree of MR task difficulty (i.e., degrees of angular orientation)?

The hypotheses that I tested were:

$H0^1$: The cognitive stressor has no effect on MR task performance.

$H1^1$: The cognitive stressor has an effect on MR task performance.

$H0^2$: The effect of the cognitive stressor is independent of the angle of orientation of the MR target figures.

$H1^2$: The effect of the cognitive stressor is not independent of the angle of orientation of the MR target figures.

Definition of Terms

*Acute stress: B*eginning abruptly with marked intensity or sharpness, then subsiding after a relatively short period (Mosby Inc., 2009).

Mental rotation: The ability to rotate mental representations of two-dimensional and three-dimensional objects (Shepard & Metzler, 1971).

Object orientation: In mental rotation and for two or three-dimensional objects, the degree of object rotation about an axis, usually in comparison to the object's original orientation (Millivojevic, Hamm, & Corballis, 2011).

Stress: The cognitive perception of exposure to an adverse physical, mental, emotional, internal or external stimuli that elicits a state of physiological or psychological strain and which an organism naturally tries to avoid (Mosby Inc., 2009).

Visual-spatial memory: Includes both short-term (i.e., visual-spatial working memory) and long-term storage and retrieval of visual representations and their spatial relationships (Shackman et al., 2006).

Visual-spatial processing: Also known as "visuospatial processing"; pertaining to the comprehension of visual representations and their spatial relationships (Mosby Inc., 2009). Often this refers to the combination or simultaneous performance of visual-spatial memory storage and retrieval, and mental rotation of stored visual information (Shackman et al., 2006; Shepard & Metzler, 1971).

Visual-spatial working memory: A form of visual-spatial memory, this term refers to the a mental cache for temporary storage of visual-spatial information, including objects, their locations, and movements in a visual scene (Garden, Cornoldi, & Logie, 2002).

Assumptions

In this study, I assumed that the level of difficulty of task stimuli can be controlled such that a directly proportional relationship between speed and accuracy of decision-making involved in MR, and task stimuli complexity will be achieved. It was also assumed that significant variations in performance speed and accuracy will be due to the experimental variable, stress. Furthermore, it was assumed that all participants will be willing, be sincere in their efforts to do well on the performance task, and will respond to questionnaires honestly.

Limitations

In this study, there were several limitations that may weaken the results of the study. The performance task stimuli were somewhat less representative of a real-world environment, as they consisted of 3-dimensional objects, but were presented on the 2-dimensional flat surface of a computer screen. The stimuli themselves were presented individually, without any other objects in the foreground or background, as one might expect in the more complex real-world environment. In addition, the stimuli consisted of figures perhaps artificial in their appearance and made of identical cubes, which are less representative of more common shapes and figures in real life. In addition to these limitations, other forms of stress, such as emotional and physical stress, were not examined in this study.

Delimitations

I made an effort to keep this study as simple as possible, and not introduce any more variables that could potentially confound or conceal the answer to the research question. The performance task was kept as short in duration, and as simple and straightforward as possible. The study was based on well-known scientific theory, and was designed to be easily replicated.

Significance of the Study

Mental rotation plays an obvious and major role in human tasks where vision is critical, such as controlling a machine such as a car, boat or aircraft. Pilots and air traffic controllers rely heavily upon MR to fly and control aircraft safely (Morelli & Burton, 2009). These same tasks can be quite stressful, as they demand constant attention and quick, accurate decisions, often negotiating around hazards such as weather conditions and other aircraft (Leifflen et al., 1997). Although there has been some research on stress, decision making, and object tracking involved with pilots and air traffic controllers (Morelli & Burton, 2009), the relationship of stress to MR involved in such tasks has not been studied specifically.

The results of this study will help inform human factors research on the relationship of stress to MR, not only that which is involved in aviation, air traffic control and avionics, but also other areas where exposure to stress is likely. One might imagine tasks such as driving a car on a winding road; navigating a ship into a crowded harbor; performing emergency surgery, and other hyper-vigilance situations where the nature of the tasks themselves could induce acute forms of stress, and where VSP, and MR in particular, play a major role.

This study includes several positive social change implications. In addition to helping to save lives in search-and-rescue and other visual-spatially demanding hypervigilance situations, this study will help improve employee testing and selection within industries where acurate MR under stress is a job-critical skill. This study could also lead to improved employee supports and interventions to manage cognitive stress in workplaces where visual-spatial tasks are predominant. Finally, this study will provide insight into VSP that will be valuable for human factors researchers interested in developing more efficient data display systems for pilots, ship captains, drivers, and other visual-spatially demanding jobs.

Summary

Mental rotation is essential to the process of identifying, assertaining and understanding the relationship of objects in a visual scene to other objects within the same space, including the observer. Some tasks which rely heavily on MR also require hypervigilance (i.e., a heightened level of arousal), and are inherently stressful, such as driving a car on a busy highway, or controlling aircraft in busy skies. It is not known if there is a direct relationship between stress and MR performance. Specifically, it is unclear to science whether the stress experienced while performing a highly visual task impedes, improves, or does nothing to the mental rotation involved in performing the task.

In this study, I sought to shed light on the relationship of cognitive stress to MR performance. Cognitive stress in the form of high cognitive load is common in some highly demanding visual-spatial tasks, such as airtraffic control (Morelli & Burton, 2009), and was used in this study as the experimental factor. The results of this study will help inform human factors researchers, and the science of cognitive psychology as it seeks to better understand the relationship of specific kinds of stress to specific kinds of tasks. Positive social change could include greater support and training for employees whose jobs involve a high degree of VSP under stressful conditions. Moreover, for pilots, airtraffic controllers, search-and-resucue crews, and other jobs requiring hyper-vigilance under stress, this study will provide insight that could contribute to saving lives.

Chapter 2: Literature Review

Introduction

In this chapter, I first examine the scientific literature regarding visual-spatial processing (VSP), which includes visual-spatial memory (VSM) and mental rotation (MR). I then discuss various physical, environmental, cognitive, and psychological stressors that may impede or even improve VSP. I then examine the nature of stress, its relationship to performance, and what is known and unknown about its involvement with higher forms of cognitive processing, including VSP. I discuss previous research on the relationship of stress to other factors of relevance to this study, such as innate factors that affect performance; decision-making; gender and age. I present studies which have successfully manipulated stress in participants, and describe ways to measure stress and MR performance. Finally, I introduce the main research question; that is, whether MR responds the same to stress as other forms of cognitive processing, or whether MR is somehow special in this regard, and responds differently.

I conducted the literature search for this study through the Walden University Library research databases, including: EBSCOhost, Academic Search Complete/Premier, Medline Full Text, Mental Measurements Yearbook, PsychINFO, PsycARTICLES, and PubMed. The literature research spanned over 100 years of literature, from 1908 to 2012; however, the vast majority of the literature cited was published within the last 10 years. Search terms that I used for this study included *visual-spatial processing, visuospatial processing, mental rotation, memory, arousal,* and *stress.*

Visual-Spatial Processing

Many researchers theorize that VSM and MR work in a serial loop, wherein visual information is rapidly processed and reprocessed, back and forth, providing us with an seemingly instant and accurate representation of our visual-spatial world. During this process, visual forms such as length, width, height, color, and spatial location of objects relative to the observer and other objects in the local environment travel to nearby areas of the brain where this information can be mentally manipulated, or rotated (Mehta, Newcomer, & Damasio, 1987; Riddoch, 1990; Suzuki, Yamadori, Hayakawa, & Fujii, 1998; Zacks, 1999). According to some models, the new mentally rotated spatial information is fed back to VSMfor recoding, where it can be retrieved again (Luzzati, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998).

The Phenomenon of MR

The nature of mental imagry has long been a focus of philosophical and scientific debate by phenomenologists and psychologists, such as Fodor (1968), Slezak (1995), and Pylyshyn (2002), to name a few. One related topic of discussion among these authors relates to whether the phenomenon of mental processing of visual imagery, such as mental rotation, is based upon tacit knowledge (i.e., knowledge of how an object should look), and decisions about the image based upon the relevant congruence of the image to tacit knowledge of the object; or, is mental imagery based on anologue, *mechanical* processes (Psylyshyn, 2002). Mental rotation, Psylyshyn appears to argue, can be viewed either as based on tacit knowledge or analogue process.

Researchers Shepherd and Metzler’s (1971) now well-known experiment with mental rotation supports the view of mental rotation as an analogue, mechanical process of the brain. These researchers presented adult participants 3-dimensional “L”-shaped figures made up of identical cubes, oriented varying degrees along their axes of rotation, and presented in pairs on a video screen. Half of the figures were mirror images of the other. Participants determined if the pairs were the same figures, only oriented differently from each other, or different, mirror images of the other.

Results from Shepherd and Metzler’s (1971) experiment showed that the greater the difference in angular orientation between pairs, the longer it took to made same or different judgements about the figures. Even phenomenologists such as Psylyshyn concede that in Shepherd and Metzler’s mental rotation studies, the target objects that participants rotated in their minds indeed appear *rotated* in a literal sense. The only real issue of debate is whether that rotation itself is how decisions about the objects were made. Psylyshyn (2002) and others argue that decisions made about mentally rotated objects come from tacit knowledge; that is, knowledge gained from personal experience with the object, or similar objects, and not gained from others, or from instruction. However, this study avoids philosophical discussion over the precise subjective nature of the phenomenon of mental rotation, and instead focuses on the action of mental rotation, which approaches the phenomenon from a literal, analogue interpretation favored by Shepherd and Metzler (1971).

Neuropsychological Mechanisms of VSP

Scientific research on VSP presents various ideas for what brain mechanisms are responsible for this processing. The majority of studies of patients with brain lesions suggest significant involvement of the right temporal-parietal region in locating, processing and storing visual-spatial information into VSM (Luzzati et al., 1998; Mehta et al., 1987; Riddoch, 1990; Suzuki et al., 1998; Zacks, 1999). This brain region is involved in encoding and holding visual information (i.e., relative locations, distances, and orientations of objects), creating a mental map of the environment.

In functional Magnetic Resonance Imaging (fMRI) studies of VSP, patterns of elevated brain activation have been found which indicate spatial coordinates of objects on this mental map appear to feed into mechanisms in the left hemisphere for MR (Riddoch, 1990; Suzuki et al., 1999). The left parietal-temporal-occipital (PTO) region, and to a lesser degree, the dorso-medial parietal systems, are believed to play a significant role in MR (Suzuki et al., 1999). The dorso-medial parietal systems are thought to be involved with the beginning phases of the larger MR process. Supporting this are fMRI studies which observed cerebral blood flow to increase from the dorso-medial parietal areas to PTO structures, while performing MR. The spatial information of the target to be rotated is initially acquired by mechanisms in the dorso-medial parietal areas then directed to the PTO region for MR (Suzuki et al., 1999).

More recent fMRI studies of MR used modern data analysis techniques to discern differences in brain activation patterns while performing mental rotation tasks, thereby helping to isolate specifc brain areas involved in mental rotation. For example, Mourao-

Miranda, Ecker, Sato, and Brammer (2009) detected strong evidence of a greater functional connectivity between the supplementary motor area, bilateral premotor area, bilateral inferior and superior parietal lobe when participants performed mental rotation of 3-dimensional L-shaped figure pairs with one figure in the pair rotated between 0 and 100 degrees from its partner. Other researchers using fMRI and mental rotation tasks similar to that used by Mourao-Miranda et al. (2009) have echoed earlier findings of studies which have shown high activation in the superior parietal lobe, very near the parieto-occipital area, as well as in the middle and superior frontal gyrus bilaterally, and the right inferior frontal gyrus (Hattemer et al., 2011).

Some studies suggest that MR is itself a separate process than that of visual memory encoding and retrieval. For example, one recent study found that dual processing consisting of MR and simultaneous response selection slows attentional shifting and short-term memory encoding, supporting the idea that visual memory and MR are not parallel processes, but rather serial processes linked together (Pannebakker et al., 2011). A feedback loop of sorts between visual memory and MR could explain why Pannebakker et al. (2011) found that MR influences the organization and placement of visual-spatial attention.

Forms of Stress

The concept of stress has generally been quite difficult to define due to the both subjective and objective nature of stress (Evans, 1982). For the purpose of this study, four categories of *acute* stress will be discussed: Physical, environmental, psychological, and cognitive.

Physical stress can be conceptualized as the perception of strain of any part of the body, such as physical pain or discomfort. Over-exercising a part of the body to the point of injury or near-injury is a form of physical stress. Essentially, any time a situation, behavior, or body process results in the perception of pain or discomfort is physical stress (Anderson, 2004).

Environmental stress (i.e., physical stressors outside of the body) occurs when any of the body's senses are exposed to high enough levels of stimuli that result in the perception of physical pain or discomfort. Examples of environmental stress include intense temperatures, such as extreme heat or cold; loud noises, such as that of jet airplane engines, or a rock concert; intensely bright lights, such as direct sunlight or other brilliant light shown in the eyes; foul or acrid smells, such as the smell of ammonia, rotting flesh, or fecal matter; and foul tastes, such as intense bitterness, or rotten food (Anderson, 2004). Psychological stress includes top-down processes that affect an individual's ability to function, and include painful or uncomfortable thoughts and feelings, including emotions such as anger, sadness, frustration, worry, etc. (Collins, Sorocco, Haala, Miller, & Lovallo, 2003). In this study, I focused on cognitive stress only.

Cognitive Stress

Cognitive stress is the sensation of being under stress due to intensive cognitive processes. It can also be considered a form of psychological stress, as cognitive stress involves mental awareness of the stressful effects caused by higher brain functions (Turpin, 2003). Cognitive stressors are well known to produce stress responses in the body, such as elevation of blood pressure, heart rate, and respiration, and elevation of stress hormones (Bremner et al., 2009; Leistad et al., 2008; Masters, Hill, Kircher, Benson, & Fallon, 2004; Neupert, Miller, & Lachman, 2006). Some examples of cognitive stress include interpersonal conflicts (Masters et al., 2004); making simple mathmatical calculations under time pressure (Neupert et al., 2006); making difficult decisions where the consequences of the decisions are great; rapidly encoding and retrieving information into memory; rapid and prolonged task shifting (i.e., rapidly moving from one different form of processing to another, and back again) while trying to maintain both speed and accuracy (Bullinger et al., 2005); and intensive concentration in the midst of other physical, environmental, and/or psychological distractors (Turpin, 2003).

Neuroanatomy of Stress

Although there is much known about many physiological mechanisms that have been shown to play a significant role in the process of stress, it is still largely a mystery as to precisely how these systems interact with each other to create the sensation of being under stress. Physiological structures known to play a large part in stress production include the hypothalamus, pituitary gland, and adrenal gland. Together, these structures create the Hypothalamus-Pituitary-Adrenal gland (HPA) axis of the stress response, also known as the *fight or flight response* (Christiansen, 2005). Through this axis, conscious and unconscious stimuli are thought to trigger the hypothalamus to generate emotions, and to release corticotrophin-releasing hormone (CRH). CRH travels from the hypothalamus to the pituitary gland causing it to release adrenocorticotropic hormone

(ACH). ACH travels through the blood and to the adrenal glands, causing these glands to release catecholamines, such as epinephrine, norepinephrine, and glucocorticoids, including the steroid cortisol (CORT). The catecholamines release increase heart rate, blood pressure, and increase blood sugar. CORT suppresses the immune system, reduces inflammation throughout the body, and also increases blood sugar (Christiansen, 2005).

Other neurological mechanisms known to be involved with stress are the hippocampus, amygdala, raphe nucleus, locus coeruleus, and the spinal cord. The hippocampus is thought to be a significant contributor to the formation of memories. It is part of the limbic system, and has connections with the amygdala, hypothalamus, and many areas of the cerebral cortex. Information from the hippocampus, especially information of a threatening or intense emotional content, can trigger the hypothalamus and potentially trigger the stress response (Christiansen, 2005). The amygdala is involved in perception of threat, fear, anger, and emotion regulation. The raphe nucleus, located near the brain stem, also has projections that connect with the hypothalamus, produces the neurotransmitter serotonin, and plays a role in controlling mood. The locus coeruleus synthesizes norepinephrine, connects to and receives messages from the amygdala, raphe nucleus, hypothalamus, and spinal cord, and is also located in the brainstem.

Theoretical Foundation: Stress and Performance

Although there have been many studies examining the effects of stress on various complex cognitive processes, such as memory or performance on computational tasks, very little research has examined the effects of stress on visual-spatial processing. Well-established theories, such as the Yerkes-Dodson Law (Yerkes & Dodson, 1908) and others that predict the relationship of stress and performance do not specifically indicate VSP as a qualifying cognitive process. However, there are studies that have found the neurological system of VSP, such as VSM performance, is indeed vulnerable to stress (Newcomer et al., 1999). Other studies have shown that response accuracy and speed are impacted by the level and duration of stress, and that for intense stressors, performance speed for cognitive tasks may increase, whereas accuracy decreases (Szalma & Hancock, 2011). It is necessary, therefore, to outline some of the prevailing theories surrounding stress and performance, and to describe sources of stress that not only differ from each other, but may also affect cognitive processes such as VSP in ways not predicted or fully described by conventional theory.

Yerkes-Dodson Law

In learning theory, it is widely understood that arousal can affect attention and motivation. One finding with respect to arousal is the Yerkes-Dodson Law (YD Law) (Yerkes & Dodson, 1908). It predicts an inverted U-shaped function between arousal and performance. Too little arousal has an inert effect on task performance, while too much has an adverse, hyperactive effect. There is an optimal level of arousal, also referred to as "U-Stress," whereby performance is maximally increased by arousal. This optimum level of arousal is lower for more difficult cognitive tasks, and higher for tasks requiring endurance and persistence (Yerkes & Dodson, 1908). However, the arousal Yerkes & and Dodson (1908) refer to does not address specifically unpleasant or stressful stimuli, such as difficult cognitive tasks under time pressure, persistent performance anxiety, or anxiety in the form of worry and fear. Arousal in the form of excited anticipation and psychological motivation may have a positive effect on performance at moderate levels, as the Yerkes-Dodson Law predicts. However, as indicated by more recent studies, moderately unpleasant, or stressful, psychological and physical stimuli can negatively impact performance on a variety of cognitive tasks (Litz et al., 1996; Gil et al., 1990; Skosnik et al., 2000). Although the Yerkes-Dodson Law applies to many forms of arousal, such as anticipation and levels of motivation, it may not apply to all forms. Moreover, it may be that visual-spatial processing behaves differently with regards to the Yerkes-Dodson Law.

Just as inherently unpleasant stimuli are stress inducing, high cognitive load increases the demands on cognitive systems (e.g., focused attention, memory, processing speed, etc.), thereby elevating arousal levels beyond baseline, increasing activation of the sympathetic nervous system, thus increasing stress (Fisher & Fadel, 2010; Mizuno, Tanaka, Yamaguti, Kajimoto, Kuratsune, & Watanabe, 2011).

Arousal Theory

Arousal theory states that performance is dependant upon both the complexity and difficulty of the task, and that the arousal threshold for optimal performance is higher for less difficult tasks (e.g., psychomotor and perceptual tasks), and lower for more difficult tasks, e.g., communication of complex thoughts and ideas, problem solving, etc. (Broadbent, 1978; Luciano et al., 2004).

Maximal Adaptability Theory

An alternate theory to consider when measuring the effects of stress on cognitive performance is maximal adaptability theory. This theory states that an individual's ability to adapt to stress and perform well decreases as more and more stressors combine (Szalma & Hancock, 2011). Similar to arousal theory, performance on more intensive cognitive tasks becomes more vulnerable to stress compared to perceptual or motor tasks, and that response accuracy will appear to suffer more greatly compared to response time (Szalma & Hancock, 2011).

Because VSP is a perceptual task, if maximal adaptability theory is correct, then a greater and more prolonged exposure to stress would be needed before one should expect a noticeable decline in task performance accuracy; whereas, reaction times should remain largely unchanged. Put another way, if the Yerkes-Dodson Law is correct with respect to perceptual tasks like VSP, then the upside-down "U"-shaped curve representing performance with respect to stress, as predicted by the Y-D law, should be somewhat skewed to the left for VSP tasks.

Composite Theory

Composite theory is a theory of the effects of noise stress on performance that predicts that performance suffers as noise interferes with inner speech, such as when working out a problem in one's mind (Szalma & Hancock, 2011). In addition, composite theory predicts that performance should decrease the longer one is exposed to the noise stress due to wearing off of the positive effects of arousal in combination with masking of inner speech (i.e., thinking in words) by the noise itself (Szalma & Hancock, 2011).

Do forms of stress other than noise interfere with inner speech? Is inner speech involved with perceptual cognitive processes such as VSP? Indeed, some earlier researchers have suggested that all forms of performance tasks should be affected by noise, no matter the type of noise (Poulton, 1981). More recent studies have shown inner speech can be at least partially masked by other forms of stress, such as the anxiety experienced during public speaking (Zohar, Livne, & Fine, 2003). Perhaps other forms of stressors interfere with inner speech in some meta-cognitive way; that is, it may be possible that the increase in masking of inner speech found by researchers such as Zohar et al. (2003) is actually the increased awareness of the stressor and subsequent increase in thinking about how to compensate for the stressor's interference.

Stress Varieties and Cognitive Performance

There is a wide range of cognitive processes that stress is known to affect. Overall, research indicates there tends to be a relationship between stress and cognition whereby positive emotions, or *positive stress,* tends to increase or improve cognitive performance, and unpleasant emotions, or *negative stress,* decreases or impedes performance (Renner & Beversdorf, 2010). Generally, the degree of positive or negative impact on cognitive performance is relative to the amount of perceived stress (Renner & Beversdorf, 2010).

Perception

One's perception of stress as "positive" or "negative" has a significant role in whether that stress improves, impedes, or does not interact with some forms of cognitive tasks. Brisswalter, Collardeau, and René, (2002) presented a meta-analysis of studies of exercise and cognitive performance which showed that for relatively simple tasks, such as perceptual tasks, a decrease in performance has been observed at all ranges of physical exercise intensity. However, when physical stress is moderate or high (e.g., indicated by maximal oxygen intake while running on a treadmill), performance improves with respect to more complex tasks such as decisional tasks. These results were independent of the level of physical fitness, and appeared more related to the onset of epinephrine release into the blood stream at the time of moderate to maximal physical stress (Brisswalter et al., 2002). Although these surprising findings may also be linked to factors such as subject confidence, lab conditions, etc., nevertheless, in light of a large body of research supporting the predictions of the Yearkes-Dodson Law, the finding by Brisswalter et al. (2002) that high stress can improve task performance with some cognitive tasks is interesting, and underscores the complexity of the relationship between stress and performance.

Some more recent research has examined how the perception of stress (perceived as undesirable or negative) can have a direct effect on the actual stress the body experiences. Jobin, Wrosch, & Scheier (2013) sampled cortisol awakening responses (CAR) of 135 older normal adults 12 different times over 6 years, and assessed whether they perceived their level of stress as higher or lower than average. CAR is the rise in cortisol levels about 30 minutes before waking from sleep, and is thought to be associated with an anticipation of stress for the new day (Jobin, Wrosch, & Scheier, 2013). According to the results of personality assessments, the participants were divided into groups of “optimists” (those who tended to see their stress as low), and “pessimists” (those who tended to perceive their stress as high). The researchers found that, surpsingly, the perception of higher stress tended to result in elevated CAR and afternoon/evening cortisol in “pessimists”, but when “optimists” indicated their stress was higher than average, CAR levels were not elevated. These results suggest that not only does perception of experiencing stress affect actual stress levels, but also the tendency to perceive something as stressful or not (i.e., personality factors) also plays an important role in the level of stress hormones produced, and the degree of stress one actually experiences; that is, the agreement of the body with the mind.

Performance Pressure

Feeling the pressure to succeed is something that most of us have felt at one time or another. The impact of performance pressure on task performance has been examined in considerable depth by researchers, particularly those interested in the psychology of professional athletes. Drive theory, sometimes referred to as “motivation theory”, is one theory which addresses the effect of performance pressure on behavior (Spence, 1958). This theory proposes that increases in arousal (or drive) increase the probability that the dominant response will occur. If the task is well learned, the dominant response is the correct or successful behavior. Thus, increasing pressure to perform well, thereby increasing drive, will elevate the level of performance. If the task is poorly learned, however, the dominant response is failure or error, and a decrease in performance will result from enhanced drive (Lewis, 1997).

One study that examined these ideas about "choking under pressure" examined healthy university students and their ability to putt a golf ball into a hole while under pressure to perform (Lewis, 1997). Subjects were given sufficient practice before trials began so that by the end of the practice session, all subjects were able to consistently putt the golf ball into the hole from a comfortable distance that varied from subject to subject.

The performance pressure took the form of videotaping subjects and informing them that their performance would be later evaluated by trained sports psychologists and golf experts. Results clearly showed that inducing performance anxiety in this way significantly reduced the level of performance. Although subjects were reasonably expert at their task (putting the golf ball into a hole), their performance nevertheless suffered as a result of induced performance anxiety.

Physiological Stress, Cortisol, and Cognitive Performance

Many studies have found that high levels of physiological stress impede encoding and retrieval of information. Other studies of stress and performance have found that some aspects of VSM may also be negatively affected. For example, Taverniers, Van Ruysseveldt, Smeets, and von Grumbkow (2010) found that high levels of the CORT affect both visual-spatial working memory and visual-spatial declarative memory. In this study, Taverniers et al. (2010) examined military special forces soldiers under the high-impact physical and psychological stress of training. The researchers used the Rey-Osterrieth Complex Figure (ROCF) test, and asked the subjects to draw a complex line drawing first by looking at the image, and then from memory alone. Taverniers et al. (2010) found that high levels of salivary CORT measured after exposure to the stressors impaired visual-spatial working memory and visual-spatial declarative memory performance.

High CORT levels can impact on many aspects of cognitive functioning, particularly on attentional processes, which are important in visual-spatial processing. One study comparing patients suffering from chronic, severe stress with normal controls found that the stressed patients exhibited impaired performance on measures of attention, as well as other cognitive measures such as intelligence, verbal fluency, and memory (Gil et al., 1990).

Psychological Stress

Psychological stress in the form of psychological trauma has been shown to impair some visual tasks (Lilley, Andrade, Turpin, Sabin-Farrell, & Holmes, 2009). One such study aimed to understand information processing in patients who had suffered exposure to the traumatic stress of military combat compared performance of these patients to normal patients on a modified version of the Stroop procedure and a threat rating task (Litz et al., 1996). Traumatically stressed patients exhibited an acute stress response (e.g. sweating, increased heart rate, and accelerated breathing) to the military-related words, and subjectively rated these words as very stressful, resulting in significantly increased response times for identifying the color of threat-related words in the Stroop procedure.

Psychosocial Stress

Psychosocial stress is a specific example of psychological stress that has been shown to negatively affect cognitive performance, specifically working memory. The effect of peer pressure and the desire to be accepted by members of one's social group can be a significant factor in cognitive performance. High levels of psychosocial stress have been shown to raise the stress hormone cortisol, and impede memory performance. For example, Oei, Everaerd, ElzingaVan Well, & Bermond, (2006) used the Trier Social Stress Test (TSST) to increase psychosocial stress. The researchers measured recall for paragraphs, and performance on an item-recognition task. The paragraphs were from the Wechsler Memory Scale-Revised Logical Memory test designed to test declarative memory. The item-recognition test presented letters on a computer screen that subjects had to memorize and recognize when presented again later. Oei et al. (2006) found that high psychosocial stress (indicated by high salivary cortisol levels) significantly impaired both paragraph recall and item recognition.

Personality and Innate Factors

It has been well established for some decades that personality factors can affect how one perceives a stressor, and the degree to which it is unpleasant or threatening, resulting in individuals tending towards a particular mood state, and thus reacting to stressful conditions in predictable ways (Larsson, 1989; Lewis, 1997). According to a cognitive model of mood state and performance, an emotional state leads to increased activation of memory representations of mood-congruent information. This results in the shift of attention towards processing of such information. Consequently, an elevated anxious mood state should result in attentional biases favoring threat stimuli in perceptual, attentional, and memory processes (Mogg, Bradley, & Hallowell, 1994). More recent experiments on the effects of stress on visual-spatial tasks support the idea that anxiety-prone individuals tend to perform poorly on such tasks (Eysenck & Payne, 2005).

High levels of stress not only tend to significantly interfere with attention, but also those individuals who tend to be anxious and easily stressed, (by virtue of being generally distracted by thoughts of stressful situations), are more likely to have difficulty focusing attention on performing a cognitive task, including at least some aspects of VSP (Eysenck & Payne, 2005).

At least for adults, this conclusion is supported by more recent studies. For example, Eysenck & and Payne (2005) examined the effects of an individual's vulnerability to stress on the visual-spatial "sketch pad", or visual-spatial working memory. Results found that those who reported to be more inherently anxious tended to perform poorly on a variety of visual tasks, including recall of mental maps, and manipulation of visual-spatial content of mental maps, compared to those who reported to be less vulnerable to anxiety. In contrast, some studies of children, anxiety factors, and VSP have found that an individual's reported vulnerability to anxiety does not appear to be a factor for accuracy of VSM tasks (Visu-Petra, Ţincaş, Cheie, & Benga, 2010).

Stress and Decision-Making

The process of making a decision is complex and involves numerous sub-processes in the brain. Not accounting for factors such as experience and intelligence, the speed and accuracy of a decision depends upon the type of decision being made and the amount and complexity of the information needed to make the decision (Kassam et al., 2009). Concerning VSP, characteristics of decision-making itself may come into play with MR, such as when making same or different judgments about shapes rotated various degrees from the original shape. For example, Cohen & Blair (1998) asked participants to compare two 2-dimensional geometric figures with one figure of each pair rotated various degrees compared to the other and decide if the figures will be the same but rotated differently, or different mirror images of each other. The focus of this study by Cohen &

Blair (1998) was to investigate the effect of a temporal contingency in the form of a loud computer beep on reaction times of same or different judgments. The computer beep sounded when the participants' mental rotation reaction times slowed to below the reaction times of 87% of participants from an earlier pilot study on mental roation the authors conducted. The authors found that participants exposed to the loud computer beep had decreased reaction times for the MR task, compared to participants in the no-temporal contingencycondition (Cohen & Blair, 1998). Although it may be reasonable to assume that the computer beep increased arousal and stress as evidenced by decreased reaction times, the authors of this study did not determine whether the computer beep was in fact stressful. Nevertheless, Cohen & Blair's (1998) study did show that decision-making response times for a mental rotation task could be improved by introducing a "loud" external stimulus (a computer beep). Thus, these findings may serve to inform other studies that investigate the relationship between decision-making andexternal stimuli that impact performance, perhaps including studies investigating decisions made during VSP tasks in the presence of a stressor.

Other factors, such as individual differences in response to stress, have been shown to affect decision-making. For example, one study found that cardiovascular response to stress mediated participant perception of a stressor as either a threat or a challenge, and affected decision-making on an anchoring-and-adjustment questionnaire (Kassam, Koslov, & Mendes, 2009). Anchoring-and-adjustment, or the complex interplay of automatic and controlled process interaction affecting decisions, beliefs, attitudes, etc., appears more cognitively complex compared to seemingly automatic, perceptual decisions made in VSP tasks. However, the study by Kassam et al. (2009) shows the importance of considering differences between individual responses to stress, as measured in this case by a physiological correlate of stress, cardiovascular efficiency.

Gender Differences in VSP

Although some studies have found that women prefer landmarks in tests of VSM involving remembering directions and navigating using an area map (e.g., a map of city streets and locations), there does not appear to be a difference between men and women for how much visual information can be held in VSM, encoding of VSM information, or VSM retrieval speed and accuracy. However, there are differences in VSM when considering other factors, such as the metric nature and degree of interaction with VSP information (Ruggiero, Sergi, & Iachini, 2008).

There is a consistent amount of research in the cognitive literature that indicates males tend to perform better than females on measures of MR. One study which used both paper and virtual environment tests of MR showed males perform significantly better on paper versions of such tests, whereas, females perform equally well compared to males for MR tests using a three-dimensional virtual reality environment (Parsons, Larson, Kratz, Thiebaux, Bluestein, Buckwalter, & Rizzo, 2004). Other studies have found that females tend to take longer to respond and make less accurate judgments for a three-dimensional MR task, compared to males (Prinzel & Freeman, 1995). As some researchers have suggested, this gender difference in MR performance may be due to the increased difficulty of the task when angle disparities between rotated objects increases substantially, for example, from 90 to 180 degrees (Prinzel & Freeman, 1995). Other studies have shown that men also tend to perform better than women on two-dimensional paper MR tasks (Collins & Kimura, 1997). However, such gender differences tend to diminish significantly when subjects are given training and practice on either two or three-dimensional MR tasks (Neubauer, Bergner, & Schatz, 2010).

Tasks for Effectively Elevating Stress Levels

By definition, any of the forms of stress mentioned above could conceivably be used in an experimental setting to induce stress, although some methods would raise obvious ethical concerns (e.g., causing physical pain). Raising stress levels causes discomfort in participants, and so the method chosen to induce stress must be carefully considered, and its value to the study judged against the discomfort it causes participants.

There are methods for inducing stress that cause no harm, and create mild to moderate discomfort that is brief, but effective for experimentally elevating stress to useful, measurable levels. For example, Hassinger, Semenchuk, and O'Brien (1999) reported that cognitive stressors, such as counting tasks under time pressure, are reliably effective for elevating stress to mild to moderate levels. One task in particular that has been used successfully to this effect is counting backwards from a large three or four-digit number by groups of odd numbers under time pressure, such as counting backwards from 7000 by 7’s (Ficek & Wittrock, 1995; Hassinger et al., 1999), or counting backwards by 7’s from a 3-digit number (Neupert et al., 2006).

Measures of Stress

Reliably measuring the degree to which a person is experiencing stressful conditions is a challenge for researchers. There are individual differences between how readily one perceives stress, how likely a person is to perceive something as stressful, and how much stress one can tolerate before reporting something as stressful (Eysenck et al., 2005; Mogg et al., 1994; Moser, Becker, & Moran, 2011; Spielberger, 1983).

Subjective measures of stress can be useful, such as surveys and questionnaires, but are also problematic for many reasons. For example, some gender stereotypes may expect the male to be able to tolerate greater amounts of stress, or tolerate stress for longer periods of time (Najam & Aslam, 2010). Social expectations and cultural values may also influence how much stress is actually reported by both men and women (Maercker, Mohiyeddini, Müller, Xie, Hui Yang, Wang, & Müller, 2009). In light of the unreliability of subjective measures, any study of the effects of stress should consider balancing less reliable subjective measures with objective measures.

Examples of objective measures of stress include mostly physiological correlates of stress, such as increases in heart rate, blood pressure, body temperature (Brisswalter, Collardeau, & René, 2002; Neupert, Miller, & Lachman, 2006), salivary cortisol levels (Oei et al., 2006), and skin electrical resistance caused by sweating, also known as galvanic skin response (Choi, Lee,Yang, Kim, Choi, Park, Jun, Tack, Lim, & Chung, 2010).

Measurements of MR

By far, the majority of studies of MR of three-dimensional figures have used stimuli the same as or similar to that developed by Shepard and Metzler (1971). Unlike some two-dimensional tests, such as that of Cooper (1975), which can only be rotated on two axes, three-dimensional figures can be rotated on three axes, and are thus believed by many researchers to be more complete measures of MR ability (Peters & Battista, 2008; Shephard & Metzler, 1988). Many studies have used variations of the Shepard-Metzler Mental Rotation Test figures to test everything from gender differences in MR performance, to hormonal influences on MR, to MR ability of military pilot candidates (Quaiser-Pohl & Lehmann, 2002; Yang, Hooven, Boynes, Gray, & Pope, 2007; Fatolitis, Jentsch, Hancock, Kennedy, & Bowers, 2010, respectively).

Although the original test by Shepard and Metzler (1971) presented its figures on a video screen, other researchers have used a paper version of this test and have found the different presentation methods do not seem to affect MR differently (Vandenberg & Kuse, 1978). Moreover, fMRI studies comparing computerized versions of three-dimensional figures used by Shephard and Metzler (1971) to paper versions of the same test figures showed these two presentations do appear to measure the same spatial behavior (Voyer, Butler, Cordero, Brake, Silbersweig, Stern, & Imperato-McGinley, 2006).

Stress and VSP

When it comes to studies of VSP as a cognitive process and its relationship to stress, the literature is quite limited, or simply nonexistent. The studies of VSP and stress that do exist examine VSM and other elements of VSP, but not MR and stress.

Within the area of gender studies and VSP, men and women have been found by some studies to perform differently in response to psychosocial stress. Thomas, Laurance, Nadel, and Jacobs (2010) pointed out the need for studies of gender differences, stress, and spatial navigation, implying the relative paucity of research on the subject of stress and VSP:

> Furthermore, no-one has investigated sex differences in the relations between acute stress and spatial navigation, even though stress affects verbal memory and decision-making performance of males and females differently. (p. 32)

Thomas et al. (2010) found that psychosocial stress induced by the Trier Social Stress Test impaired females' spatiotemporal encoding and wayfinding in a virtual reality navigation task, but not landmark-guided navigation; whereas, there was no effect of the stressor on male subjects.

There has been some recent investigation of anxiety effects on VSP in children that found spatial orientation impairment for anxiety disordered children on a virtual, computer-based task comparable to the Morris Water Maze task (Mueller,Temple, Cornwell, Grillon, Pine, & Ernst, 2009). Although the findings by Mueller et al. (2009) contribute to the study of VSP and stress, the study focuses on a specific clinical domain of pediatrics, and not normal adult populations. Furthermore, Mueller et al. (2009) looked specifically at presumably chronic anxiety as manifested in anxiety disorders, and not acute, or mild to moderate stress.

Other researchers who have examined some elements of VSP and stress in adults have examined only one form of VSP, such as VSM. For example, one study examined the effect of artificially elevated carbon dioxide levels on visual-spatial performance involved in the Manikin Test (Bailey, Papadopoulos, Lingford-Hughes, & Nutt, 2007). The Manikin Test uses a computer display of a manikin in various positions, and at various distances from the observer. The manikin has an object, such as a red ball, in one hand. The subject's task is to identify which hand the ball is held. This task could be considered a form of MR task, as it requires some form of mental shifting of visual perspective to determine which hand the ball is located. However, the Manikin Test combines other elements of visual processing, such as perceived relative distance, identification of colored balls, etc., and was intended to measure VSP speed, and not necessarily MR specifically (Bailey et al., 2007; Gilhooly, Wynn, Phillips, Logie, & Della Sala, 2002). Moreover, the Manikin Test has mainly been used for highly specific applications, such as tests of the effects of hypoxia on VSP performance associated with aircraft pilots (Leifflen, Poquin, Savourey, Barraud, Raphel, & Bittel, 1997), and not to study the effects of acute forms of stress on specific forms of VSP.

Many studies have found that high levels of stress impede encoding and retrieval of information in working memory. Indeed, the idea that high stress impedes memory performance for a wide variety of tasks is well known to cognitive science (Deyzac, Logie, & Denis, 2006; Eysenck, Payne, & Derakshan, 2005; Litz, Weathers, Monaco, & Herman, 1996; Newcomer, Selke, Melson, Hershey, Craft, Richards, & Alderson, 1999). Although a few researchers have examined the effects of stress on one component of VSP, VSM (Taverniers et al., 2010), little or nothing is known of the impact of stress on MR specifically.

Neurological studies of the role of specific brain areas in how they attend to emotional arousal and threat have yielded interesting findings. For example, Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric, and Davidson (2006) found that threat-induced anxiety disrupted performance for a VSM task, but not verbal working memory. Shackman et al. (2006) echoed the conclusions of other researchers that the difference in task performance they observed was due to hemispheric asymmetry in the brain, and its affect on cognitive tasks in the presence of anxiety. Specifically, the posterior parietal cortex (PPC), believed to be the center of VSP, forms a network with the right prefrontal cortex (PFC) (Pizzagalli, Shackman & Davidson, 2003). Resources of the right PFC become taxed when attending to threat conditions, and so are less available for VSM tasks (Shackman et al., 2006). These authors seem to be suggesting that VSP may be special concerning other cognitive tasks, insofar as how they respond to forms of stress; moreover, that such differences may have a purely neurological basis.

Summary

In the face of the many studies of stress and memory performance, high levels of stress impeding VSM as found by studies like those of Shackman (2006) and Taverniers et al. (2010) is hardly surprising, given the known vulnerability of memory processes to high stress levels. However, there remains the question of whether mild to moderate stress affects VSP as a whole, affects VSM and MR separately, or affects either at all. In addition, it remains unknown if mild to moderate stressors impact VSP in a way that conforms to the Yerkes-Dodson Law (1908), as some tests of neurological mechanisms, stress, and cognition suggest (Mair, Onos, & Hembrook, 2011), or is a special form of cognitive process that behaves differently in response to stress.

If visual-spatial processing areas of the brain are indeed connected in serial through mood regulatory systems to attentional control areas such as the right-PFC, as researchers such as Pannebakker et al. (2011) have found, then it might seem reasonable to assume stress affects all forms of VSP in much the same way as with other forms of cognition, as researchers such as Pizzagalli (2003) and Shackman et al. (2006) seem to suggest. However, the literature is unclear if this suggestion is in fact correct. Moreover, the literature is severely lacking with regards to studies of MR and stress; although there are studies which suggest decision reaction times for various cognitive tasks are affected by stress, there are no studies which have specifically looked at stress and reaction times for MR decisions. Even if one could argue that, because it is a cognitive process, reaction times for MR must be affected by stress, reaction times alone are not synonymous with accuracy.

Although the literature does suggest the relationship of stress and VSM, whether mild, moderate, or severe, is much like other forms of cognition, there is not yet evidence to suggest that MR behaves in the same way in response to stress. Although researchers such as Kassam (2009) and Porcelli, & Delgado (2009) illustrate the importance of task difficulty with regards to speed and accuracy in decision-making, the relationship of decision-making involved in MR to mild or moderate forms of arousal also remains unknown.

From the many studies of mild to severe stress and its impact on both attention and VSP, it appears that relatively high levels of stress may overload cognitive systems, diverting attention and so affecting cognitive tasks that rely on focused attention (Gil et al., 1990; Litz et al., 1996; Mogg et al., 1994; Newcomer et al., 1999; Shackman, 2006;

Taverniers et al., 2010). More research is needed to help clarify the effects of more moderate forms of stress in relation to VSP in general, and MR specifically.

Chapter 3: Research Method

Introduction

In this chapter, I describe the the research question and hypothesis, the research design and methodology, and the research setting and sample. In addition, I also explain the experiment procedure, instrumentation and materials, data collection and analysis, and ethical considerations regarding the use and protection of human participants. The rationale for the chosen study design is explained, a description of the validity and reliability of the instruments used, and the concepts measured by the instruments are provided. This study examined the effect of mild to moderate stress in the form of artificially elevated cognitive load on MR, consistent with other studies that have used cognitive stressors as an experimental factor in studies of performance (Cohen & Blair, 1988; Ficek & Wittrock, 1995; Gil et al., 1990; Hassinger et al., 1999; Litz et al., 1996; Newcomer et al., 1999; Oei et al., 2006; Szalma & Hancock, 2011; Taverniers et al., 2010).

Research Questions and Hypotheses

The research questions were:

1. Are there differences in MR task performance between the stress and the no-stress groups?
2. If yes, is MR performance improved by the stressor, impaired, or unchanged?
3. Is the effect of stress related to the degree of MR task difficulty (i.e., degrees of angular orientation)?

The independent variable was: Experimental condition with two levels: (a) exposure to the counting task stressor, and (b) nonexposure to the counting task stressor.

The dependent variables were MR task performance (percent correct), and response time. The hypotheses tested were:

$H0^{1}$: The cognitive stressor has no effect on MR task performance.

$H1^{1}$: The cognitive stressor has an effect on MR task performance.

$H0^{2}$: The effect of the cognitive stressor is independent of the angle of orientation of the MR target figures.

$H1^{2}$: The effect of the cognitive stressor is not independent of the angle of orientation of the MR target figures.

Research Design and Approach

I used a 1 X 2 factorial design for this quantitative study to examine the effect of mild to moderate cognitive stress in the form of a math task under time pressure on a simulated 3-dimensional MR task (presented on a 2-dimensional computer screen). Participants were 20 healthy adults 18 to 65 to 65 years of age from the local Savannah, Georgia area, including students of Mercer University School of Medicine, South University, Armstrong Atlantic State University, and Savannah Technical College. Originally, 60 participants were planned for this study, in order to detect a medium effect size. However, due to great difficulty recruiting participants, and the time and expense it would take for recruiting, it was decided that 20 participants would be sufficient, which still allowed for detection of a moderate effect size (calculated in the following section).

This study consisted of three main phases:

1. Preexperiment phase,
2. Experiment phase, and
3. Postexperiment phase.

During the prestudy phase, the participants were introduced to the study, participant consent was obtained, and demographic information was collected. Although the consent form indicated that the participants may stop the study at any time, after the consent form was signed, all participants were also verbally informed of their right to discontinue with the experiment. The experiment phase began with a baseline measurement of the participant's heart rate through use of a heart rate monitor worn on the nondominant wrist. Measuring heart rate was necessary for assessment of the math task's effectiveness at elevating cognitive load, and thus stress.

Following baseline heart rate measurement, I instructed participants on how the counting task stressor would work. I told participants that before each MR task, they were to count in pace with an electronic metronome, backward by sevens in descending order from 7000, out loud and continuously. This counting task was similar to methods used by other studies that induced stress by increasing cognitive load (Camos & Barrouillet, 2004; Ingram et al., 2000; Lagman, 2000; Reisberg, 1983). For the control group, however, participants were asked to engage in a simple counting task, counting forward from 1 to as high as they could go, and counting at a pace comfortable to the individual.

In addition, I provided instructions for performing the MR task, followed by 10 practice examples, or until the participant indicated he or she understood the instructions and examples. The experimental procedure itself followed. The main measures for this experiment were respone time and percent correct for a MR task of 3-dimensional L-shaped objects presented on a 2-dimensional computer display.

The postexperiment phase consisted of debriefing and payment of compensation to participants in the amount of $25.00 USD. I gave participants the same amount of compensation for completion of the experiment and debriefing, regardless of task performance speed or accuracy. The total estimated time for this experiment was 35 minutes: 10 minutes for Phase 1, 15 minutes for Phase 2, and 10 minutes for Phase 3.

Setting and Sample

The experiment took place within a small office, approximately 150 square feet, located at 1915 Eisenhower Drive, Savannah, Georgia. The study consisted of 20 adult (6 female, 14 male) Savannah area college students and private area residents, recruited from the Savannah area through newspaper advertisements, postings on university campuses, and direct solicitation though e-mail. I determined the sample size using two groups (experimental and control), with a Cohen's d of .50 for a moderate effect size, a power value of .70, and an alpha of .05. The sample size table for a 2 group analysis of variance indicate a total sample size of n = 20 as adequate for this controlled experiment.

Procedure

At the beginning of the experiment phase, I measured all participants' baseline heart rates using the heart rate monitor, which was strapped to the right wrist like a watch. Subjects reported which hand was their dominant hand. The heart rate monitor was strapped to the index finger of the non-dominant hand to allow the dominant hand to be unimpeded during the MR peformance task. Placing the index finger on the face of the device for several seconds operates this heart rate monitor. For both the control and experimental groups, heart rate was again measured immediately following each trial of the experiment.

For the stress condition, participants performed the counting task as described above in Research Design and Approach. These participants were prompted to count backwards from 7000 by 7s, in pace with an electronic metronome for a period of 3 minutes at the beginning of the first trial, and 1 minute each before each additional trial. There was no metronome to control the counting pace of the control participants; they counted forwards from 1, for 3 minutes, and at a normal and comfortable pace for each individual.

In addition to baseline heart rate measurement before the experiment, I also measured heart rate immediately before and after each additional 1-minute counting task to assess the effectiveness of the stressor. The metronome was set at 40 beats per minute, and the pace was indicated by both a tone and a small red light moving back and forth. Every fourth beat in the cycle was indicated by a small green light, and a higher pitched tone. The participant was to give his or her answer every time he or she saw the green light, which resulted in a pace of 20 instead of 40 beats per minute (or one answer every 3 seconds). Similar techniques have been shown effective for inducing mild to moderate feelings of stress in participants of previous studies (Hassinger, Semenchuk, & O'Brien, 1999).

During the counting task for the stress group, I provided participants with occasional verbal prompting to maintain pace. In addition, I paused stress group participants during their counting, and made them begin counting again from another number. I did this to help prevent participants from simply making up responses during the counting task

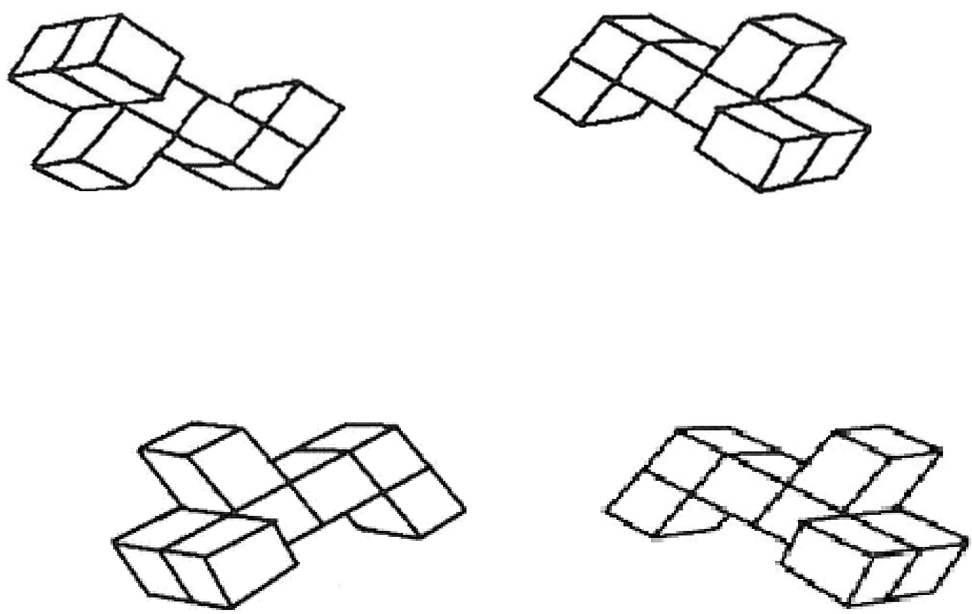
Immediately following the administration of the counting task stressor, participants directed their attention to the computer for the first trial of the performance task. The counting task stressor was administered before each performance task trial. I told participants to read the instructions for the performance task and begin by pressing any key when ready.

The MR task consisted of four blocks of trials presented on a computer screen, and took approximately 10 minutes to complete. The viewing distance of the computer screen from the participant was approximately 2 feet, and if necessary, was adjusted by the experimenter to a distance the participant found comfortable, and which allowed for comfortable access to the computer keyboard. The participants were required to maintain fixation on a single point on the screen, but rather they were instructed to move their eyes freely and as necessary to complete the performance task. The order of blocks given were alternated for every participant to prevent order effects. Participants were presented with 20 pairs of standard three-dimensional cube figures, similar to those used by Shepard and Metzler (1988; See Figure 1).

Same or Different Judgments

A.

B.



A.: These objects are the same, only rotated differently.
B.: These objects are different, mirror images of the other.

Figure 1. Sample stimuli for mental rotation task.

In order to account for various levels of difficulty mentally rotating objects, I divided the 20 pairs of figures into 4 blocks of trials each consisting of 5 figure pairs, and each block was presented the figures in a different angular orientation relative to each other, and in radomized order: 0, 45, 90, 135, and 180 degrees (5 figures of each angular orientation). There was no delay or distractor between trials, and each pair was presented one at a time. Task instructions were presented on the computer with three practice example pairs given. The experiment began immediately upon completion of the practice examples. Participants were allowed to ask questions during the practice, but I instructed them not to ask any further questions once the task had begun.

I instructed the participants to decide if the figures in each pair were the same or different from each other, and were instructed to make their responses as quickly and accurately as possible. Participants indicated their responses by pressing the "s" key on the computer keyboard for "same" or "d" key for "different". Same pairs were defined to differ only in angular rotation; whereas different pairs were defined as mirror images of each other in addition to differing in angular rotation. The structural proportions of the figures to each other were identical. The participants' percent of correct responses and reaction times for responses were recorded automatically by the computer and collected for analysis.

Instrumentation and Materials

An HP Pavilion m7 Notebook computer with a 17" color display was used to present the MR task, and used E-Prime 2.0 laboratory software for social sciences to present and record response times and performance on the MR task. A Sportline S7 Slim Heart Rate Monitor was used to track participant heart rate as a function of participant response to the stressor, and the MR performance task. For the counting task under time pressure, a MR800 Matrix Quartz Metronome was used to present flashing lights and tones to establish the required counting pace for participants.

I used a screening questionnaire to identify suitable participants for the experiment. The questionnaire was emailed to those who responded to recruitment adverstisements and who indicated interest in participating in this experiment. The questionnaire was completed by the respondans and emailed back to the researcher for review. This questionnaire asked questions about medical and mental health history, specifically, vulnerabilities to stress, vision problems, and any physical or neuropsychological problems that would potentially confound the results, or cause difficulties for the participant during the experiment. In addition, all participants provided demographic information during the screening interview, which included age, gender, education, and occupation (See Appendix A).

Data Collection and Analysis

Participants were randomly assigned into either the experimental or control conditions. The experimental condition consisted of a counting task under time pressure; the no-stress condition contained no such stressor. I used a 1 (MR task) x 2 (stress; no stress) between subjects design in this study.

I conducted the data analysis using IBM SPSS Statistics 19 software. Analyses for this study includes descriptive statistics (e.g., mean, median, mode, standard deviation, frequency, and percentage) for the dependent variables (response time and percent correct), and for demographic data, such as age and gender. A statistical comparison between the stress and no-stress groups was made using a two-sample t test to compare MR task performance (percent correct) and reponse times (measured in miliseconds) both for each individual trial, and for performance overall. In addition, a 2 x2 mixed Repeated Measures ANOVA was conducted to examine heart rate changes following the counting tasks, an assessment of the effectiveness of the stressor. Finally, a 2 (stress, control) x 5 (Angles of orientation 0, 45, 90, 135, 180) ANOVA was conducted to examine the effect of the degrees of angular orientation of the target stimuli on task performance.

Threats to Validity

The construct of mental rotation as a separate cognitive process that is yet integrated into the process of visual-spatial cognition may not be as well defined as it could be. Although studies by researchers such as Shepard and Metzler (1971) showed fairly conclusively that MR is a distinct, anlogue process, other theorists such as Psylyshyn (2002) have argued that MR is more of a manifestation of knowledge of what an object should look like and how it should behave, combined with memory and decision-making. Other threats to validity include the construct of cognitive load, and stress itself. Although it can be argued that cognitive load can produce cognitive stress, the scientific literature appears inconclusive when it comes to showing that cognitive load is itself a form of stress.

Learning effects could have also occurred in this study with regards to the performance task, and the stressor. Having practiced the performance task both during the pre-experiment phase, and after the first or second trial, it is possible that subsequent trials may have been impacted by this effect. Similarly, the counting task may have become easier after the first exposure, and thus less stress-inducing.

Another possible threat to validity is the location where the study was conducted. The office in which the participants engaged in the experiment was not a true laboratory; that is, during the day, it was used as an administrative office. Furthermore, the office was located on the campus of a state mental hospital. Although there were no patients anywhere near the the location of the experiment, the hospital was well known to the community. Some of the participants may have had feelings about the hospital, or about the mentally ill, that may have somehow affected their performance and level of participation and cooperation.

Finally, the performance task stimuli used in this study were modified stimuli used by Shephard and Metzler (1971). The stimuli were modified for copyright reasons, not scientific ones. Although the modified stimuli only varied by one small fragment, and the axes of rotation of the stimuli allowed for precise angular manipulation, the small shape difference may have been large enough to cause a difference in results, compared to similar studies which used the exact same “L”-shape design as Shephard & Metzler (1971).

Ethical Considerations

Walden University’s Institutional Review Board (IRB) standards of ethical practice in research were maintained, and an IRB approval number obtained. The rules and standards of research involving human participants (American Psychological Association, 2002) were complied with, as will be the standards and principles of the Code of Conduct (2002). Informed consent was obtained for all participants upon their arrival to the experiment location. Data was anonymous, and kept on a password-protected, stand-alone (nonnetworked) couputer within a locked private office on a hospital campus. Only I had access to the office, computer, and computer password.

Participants were informed of possible risks associated with the experiment. The main risk associated with this experiment was the potential for the participant to experience high levels of stress during the counting task that may have been higher than the participant was willing to tolerate. Participants were informed of all risks related to the experiment, and that they could discontinue the experiment at any time. In the consent form, participants were assured that no information that could identify them individually was to be collected, and that all research data collected was to be safely secured by the experimenter, and used solely for the purpose of the experiment.

Summary

I examined the effect of mild to moderate stress on MR using a 1 X 2 factorial design. The stressor was in the form of a math task under time pressure. Participant heart rate was the measure of the stressor's effect. Participants were 20 healthy adults aged 18 to 65 from the greater Savannah, Georgia area.

I addressed three research questions with this study. First, are there differences in MR task performance between the stress and the no-stress groups? Second, if there are differences, is MR performance improved by the stressor, impaired, or unchanged? Third, is the effect of stress related to the degree of MR task difficulty (i.e., degrees of angular orientation)?

I divided this study into 3 phases. The first phase involved introduction, instruction, and practice; the second was the experimental phase; and the third phase was the debriefing. Simulated 3-dimensional L-shaped figures were presented in pairs on a 2-dimensional computer screen, and were oriented at varying degrees from each other. Participants were tasked to determine as quickly as possible whether the figures in each pair were the same figures, only oriented differently, or different mirror images of the other. The dependent variables were MR task performance (percent correct), and response time. The independent variable was the experimental condition with 2 parts, stress and no-stress.

I used descriptive statistics, such as mean, standard deviation, frequency, etc., to describe demographic data, and the dependent variables. A two-sample t test was used to compare task performance and reaction time of the experimental and control groups. A 2 x 5 ANOVA was used to determine if the effect of stress on performance as a function of angular orientation. Finally, I used a 2 x 2 mixed Repeated Measures ANOVA to determine the effectiveness of the stressor at elevating heart rate, and thus stress.

There were several threats to validity in this study. The constructs of mental rotation and cognitive load were not as well-defined in the literature as perhaps they could be. There were questions about how learning effects and the location of experiment could impact performance task results. And, the performance task stimuli were slightly different compared to other studies which have examined MR. Finally, there were some ethical concerns for this study. However unlikely, the main ethical issue was the risk that some participants may have found the stressor to be too effective, producing excessive discomfort for the participants.

Chapter 4: Results

Introduction

The purpose of this study was to examine the effects of stress on performance of a mental rotation task. This chapter describes the demographics of the participants, how the data was prepared and analyzed, and presents statistical results of the experiment. The three research questions were:

1. Are there differences in MR task performance between the stress and the no-stress groups?
2. If yes, is MR performance improved by the stressor, impaired, or unchanged?
3. Is the effect of stress related to the degree of MR task difficulty (i.e., degrees of angular orientation)?

Although there are three research questions (RQ's), one statistical analysis was used to answer both RQ1 and RQ2.

The independent variable was: an experimental condition with two levels: (a) exposure to the counting task stressor, and (b) nonexposure to the counting task stressor. Angle of orientation of the MR target figures.

The dependent variables were MR task performance (percent correct) and response time. The hypotheses tested in this mixed ANOVA were:

$H0^1$: The cognitive stressor has no effect on MR task performance.

$H1^1$: The cognitive stressor has an effect on MR task performance.

$H0^2$: The effect of the cognitive stressor is independent of the angle of orientation of the MR target figures.

$H1^2$: The effect of the cognitive stressor is not independent of the angle of orientation of the MR target figures.

Data Collection

Recruitment of participants for this study was challenging. I used a combination of newspaper advertisements and fliers placed in public areas to recruit participants. The advertisements and fliers asked potential participants to email the experimenter expressing their interest in participating in the study. Then, I responded to the participant by emailing ~~a~~ questionnaire that I designed to screen for individuals who might not be able to perform the tasks given in the experiment, or might be medically inappropriate for the experiment, e.g. have a medical condition that makes them especially vulnerable to stress.

I designed the screening questionaire to I capture demographic information; participant sensitivity to stress; estimated stress from the counting tasks; possible stress-related medical information (e.g., hypertention and cardiac disease; and demographic information, such as age, gender, and occupation). Questions relating to stress were virtually the same between groups for all participants. In addition, all participants in the study indicated they were able to perform all tasks required by the study.

Recruitment response was slow and time-consuming, with an average of only five participants per month completing the experiment. With this recruitment rate, it became clear that obtaining the originally planned sample size of 60 participants would not be feasible with regards to time or expense. Calculating sample size for a power value of .70, and a moderate effect size of .50, showed that 20 participants was adequate.

Moreover, other researchers studying mental rotation have used similar sample sizes (Shepard & Metzler, 1988). Therefore, I decided that a sample size of 20 would be the most practical sample size for this controlled experiment.

There were no adverse events or any events that required the termination of the experiment. However, there was one participant whose data was not included. This participant's heart rate could not be accurately measured due to the individual's very small wrist diameter, causing the heart rate monitor to lose contact with the skin. In addition, this same individual talked and laughed during the experiment, which resulted in very high reaction times, and a task performance no better than chance.

No respondants who completed the screening questionnaire were excluded from the study participant pool. However, five repsondants completed the screening questionnaire but failed to show up to participate in the study. No respondants indicated an active medical or mental health diagnosis. Two respondants indicated histories of hypertension. The sample consisted of 20 healthy adults, (14 males and 6 females), aged 24 to 63 years (see Table 1).

Table 1

Age and Gender of Study Participants by Group

Group	Age bracket (years)	Female n	Female %	Male n	Male %	Total n	Total %
Experimental	24-30	1	10	3	30	4	40
	31-40	0	-	3	30	3	30
	41-50	0	-	0	-	0	-
	51-60	0	-	3	30	3	30
	> 60	0	-	0	-	0	-
Control	24-30	2	20	3	30	5	50
	31-40	0	-	1	10	1	10
	41-50	2	20	0	-	2	20
	51-60	0	-	1	10	2	20
	> 60	1	10	0	-	0	-
Total		6	30	14	70	20	

Note. The percentages column refers to the proportion of each gender in each age bracket.

Table 2 presents participant stated occupations, which were varied and fairly typical for the Savannah, Georgia area (USBLS, 2013).

Table 2

Participant Stated Occupations by Group

Group	Occupation	Frequency	Percent
Experimental	Bartender	1	10
	Corrections Officer	1	10
	Medical Professional	3	30
	Social Worker	1	10
	College Student	2	20
	Retired Teacher	1	10
	Computer Network Engineer	1	10
Control	Business Manager	1	10
	Medical Professional	3	30
	Student	1	10
	Teacher	2	20
	Unemployed	3	30
Total		20	

Screening questions related to participant subjective estimations of stress tolerance were rated on a 1 to 7 scale, with 1 meaning *not at all tolerant*, and 7 meaning *extremely tolerant*. Questions related to participant estimations of how stressful they would find elements of the experiment were also rated on a 1 to 7 scale, with 1 meaning *not at all stressful*, and 7 meaning *extremely stressfu*l. Both the control and experimental groups reported they were generally good at tolerating stress ($M = 5.3$), and rated performing a counting task under time pressure as only “somewhat stressful” ($M = 3.2$; see Table 3).

Table 3

Screening Questions: Self-Reported Stress Tolerance by Group

Group	N	Min.	Max.	Mean/SD
Experimental				
How well do you generally tolerate stress?	10	3	6	5.30/1.05
Stress of math task.	10	2	5	3.20/1.22
Stress of performance tasks on a computer.	10	1	5	3.00/1.15
Stress of performing simple computer task in 150sq ft office.	10	1	5	2.00/1.33
Stress of having experimenter present in office during task.	10	1	5	2.40/1.26
Control				
How well do you generally tolerate stress?	10	4	7	5.30/1.05
Stress of math task.	10	1	5	3.20/1.31
Stress of performance tasks on a computer.	10	1	4	2.20/1.03
Stress of performing simple computer task in 150sq ft office.	10	1	6	2.50/1.71
Stress of having experimenter present in office during task.	10	1	3	2.30/1.67

The remaining questions on the questionnaire screened for any physical or mental impairments that could potentially confound the experiment's results, or potentially cause greater than minimal risk to the participant. Overall, participants reported good mental and physical health. However, five participants reported either hypertension under control of medication, or hypertension in the past, but it no longer required control by medication. Two participants reported problems with memory and concentration; however, when questioned about this, these participants stated the problem was very mild, intermittant, and they did not have a diagnosis. Moreover, these participants reported they were not having memory or concentration problems at the time of the experiment. Two participants did not respond to the remaining questions about physical and mental health histories (see Table 4).

Table 4

Additional Screening Questions by Group

Group	Experimental		Control		
Screening question	Yes	No	Yes	No	Total
Can you easily use a computer mouse and keyboard?	10	0	10	0	20
Easily count forward from 1 for 3 minutes?	10	0	10	0	20
Can you count backwards from 7000 by 7's?	10	0	9	1	20
20/20 vision?	10	0	10	2	20
Difficulty with short-term memory?	0	10	2	8	20
Difficulty with long-term memory?	0	10	2	8	20
Concentration?	1	9	2	8	20
Problem solving?	0	10	0	10	20
Logical reasoning?	0	10	0	10	20
Cardiovascular disease?	0	10	0	8	18*

(table continues)

Screening question					
History of Heart attack?	0	10	0	8	18*
High blood pressure?	2	8	3	5	18*
Stroke?	0	10	0	8	18*
Head trauma?	0	10	0	8	18*
Eye trauma?	0	10	0	8	18*
Anxiety disorder?	1	9	0	8	18*
Depression?	0	10	1	7	18*
Other mental health	0	10	1	7	18*
Other neurological disorder?	0	10	0	8	18*

Note. * indicates lack of response from two participants.

Data Preparation

The assumptions for statistical analysis of this data were as follows:

1. The distributions of dependent variables for both groups are normal.
    i. Specifically, neither group has a skewness > 1, or kurtosis > 3.
    ii. The distributions of dependent variables approximate a normal curve.
2. There are no significant outliers (individual data points).
3. Variances between groups are homogeneous.

I explored the data and found it to violate statistical assumption 1a. and 1b. for the continuous dependent variable Reaction Time (RT; see Figure 2).

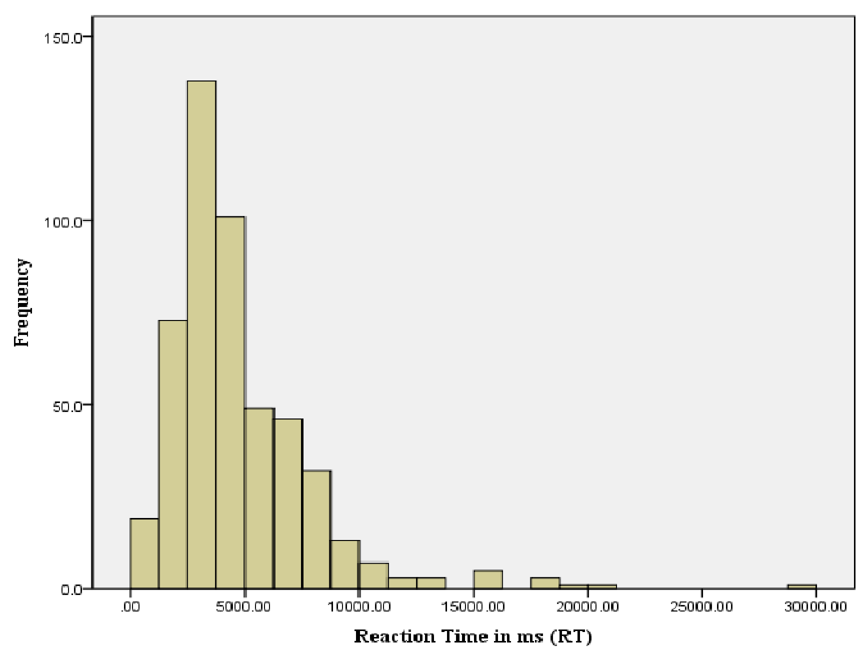


Figure 2. Histogram showing distribution of RT for both groups before removal of outliers.

Examination of RT showed a skewness value of -.207 for the Stress group, and 2.99 for the Control group. Kurtosis measured -1.22 for the Stress group, and 9.23 for the Control group. Initially, 6 RT data points were removed due to participant error, which included unintentional pressing of the response key and responding too quickly; and responding too late due to the participant adjusting their sitting positions, or asking the experimenter questions. After the removal of these outliers, data cleaning continued with the calculation of Mahalanobis Distance. Mahalanobis Distance values were compared to a Chi Square critical value of 3.84. Statistical assumpton 2 was violated after sorting of the Mahalanobis Distance values revealed 14 extreme individual RT data points. These extreme values of individual response times ranged between between 9 and 29 seconds. Once these outliers were removed, the RT data was reexamined and found to still contain a positive skew for both groups (see Figure 3); therefore, additional methods for cleaning reaction time data were explored and implemented.

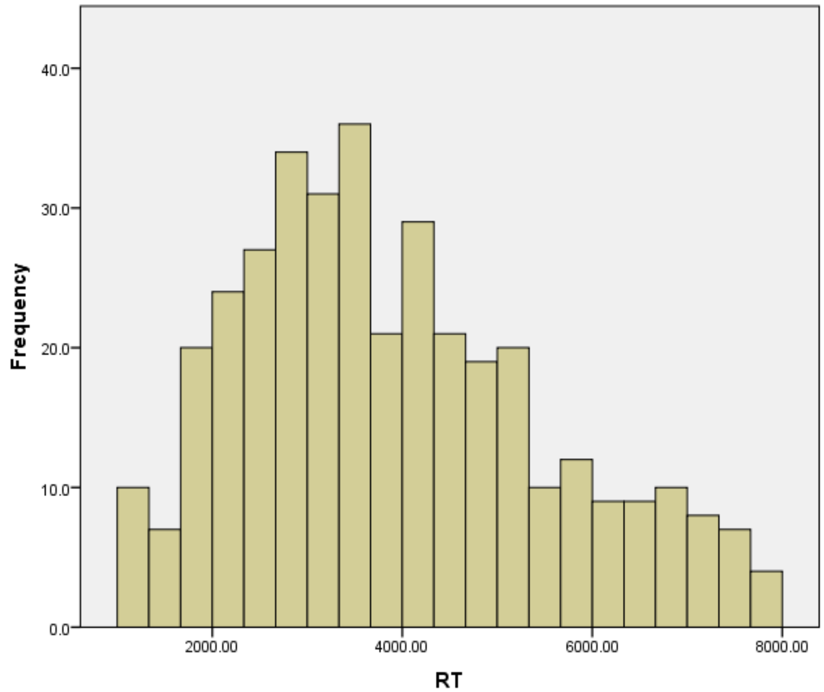


Figure 3. Histogram showing distribution of RT for both groups after removal of extreme RT data points greater than Mahalanobis Distance values of 3.84.

Implementation of Median Absolute Deviation

There are a variety methods with which to detect reaction time outliers and create a more normal distribution suitable for statistical testing (Leys, Ley, Klein, Bernard, & Licata, 2013; Ratcliff, 1993; Whelan, 2008). Leys et al. (2013) argue in favor of using the absolute deviation around the median, also referred to as the Median Absolute Deviation, or MAD. Using the MAD helps avoid problems associated with using the mean and standard deviation, such as assuming the distribution of reaction times is normal; the effects of outliers on the mean and standard deviation; and the difficulty of detecting outliers using mean and standard deviation in small sample sizes (Leys et al., 2013). Therefore, this study calculated the *MAD*. As other researchers have suggested when using reaction time data (Miller, 1991), a conservative value of 3.0 deviations around the median was chosen to calculate the cutoff values for RT. This created the following equation for the threshold for outliers: M – 3(*MAD*) < RT < *M* + 3(*MAD*), where *M* is the median of the RT series. *MAD* =1425.52, and *M* = 3708.5, yielding an interval of -568 < RT < 7985. Using this threshold interval, all RT data above 7985ms were removed. This resulted in the deletion of 12 additional RT data points, for a total of 32 (8% of the original RT data total) excluded.

Using *MAD* to detect and remove outliers following use of Mahalanobis Distance did help normalize the distribution; however, there was still a slight positive skew. As Whelan (2008) and other researchers studying reaction time have recommended, several transformations of RT were calculated. The square root of reaction time (Sqrt_RT) was found to violate none of the statistical assumptions. Examination of Sqrt_RT found it to be more normally distributed than RT. The Stress group Sqrt_RT measured a skewness of .1 and kurtosis of -.7 (See Figure 3). The Control group measured a skewness of .27, and kurtosis of -.65 (see Figure 4).

Because of the many ways researchers analyze reaction time data, the results for both untransformed RT and Sqrt_RT were reported.

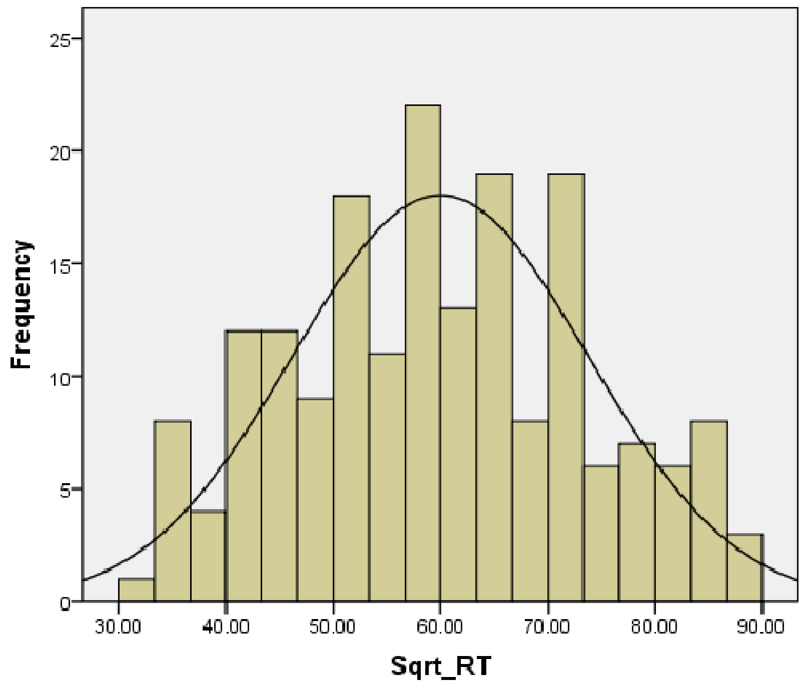


Figure 4. The distribution of transformed reaction time (RT) for Stress group.

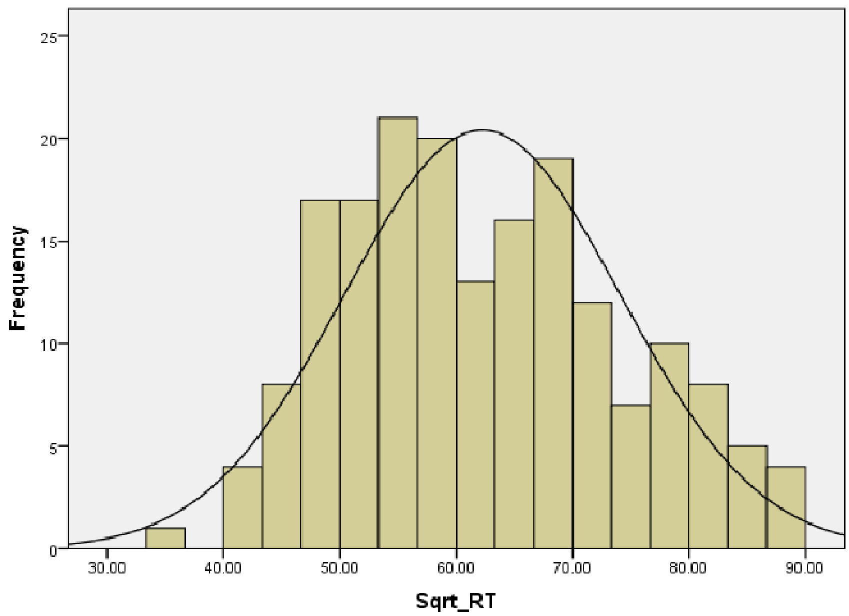


Figure 5. The distribution of transformed reaction time (RT) for Control group.

Examination of the second dependent variable Percent Correct (PC) found the distribution to be relatively normal, with a slight skewness value of -1.06, and kurtosis of .45. Because of the small sample size, and because this skewness is not unexpected from percent correct data, it was decided the percent correct variable did not require transformation.

Data Analysis

Effectiveness of Stressor

The first analysis aimed to determine if the stressor (counting backwards by 7 from 7000 to the pace of an electronic metronome) was indeed effective at creating stress as indicated by increased participant heart rates. A 2 x 2 mixed Repeated Measures

ANOVA was conducted using baseline heartrate (BHR) and heartrate measured before each trial (HR) as two levels for the dependent variable, and labled "Heart_Rate". The experimental and control groups were entered as the independent variable, "Group". Results indicated a significant interaction between Group and Heart_Rate $F(2,78) = 7.88$, $p < .01$. HR differed significantly from BHR for the Stress group compared to the Control group $F(1,78) = 5.841$, $p = .018$.

Although this analysis showed the mean differences in Heart_Rate were significantly different between both groups, the strength of the stressor was not clear; that is, the difference between BHR and HR within each group needed to be examined separtely and tested for significance. Therefore, two paired-sample T-tests were conducted comparing mean differences between BHR and HR. This was done by filtering out one group and running the paired samples t-test for the group that remained. Both groups were tested this way. The results showed that HR remained virtually unchanged from BHR for the Control group, with a mean difference of less than one heart beat per minute. However, HR did change significantly from BHR following exposure to the stressor, with a mean increase of 3.5 heart beats per minute, $t(39) = -4.11$, $p < .001$.

Differences in Performance

Reaction time (RT), and percent correct (PC) were the two dependent variables comprising performance, and the main focus of this experiment. Independent-samples t-tests were used to analyze differences between groups. Both groups' performances were nearly identical for PC $t(18) = -.261$, $p = .797$ (See Figure 5). In addition, there was no significant difference between groups for Sqrt_RT $t(366) = -1.69$, $p = .07$.

In actual miliseconds, the mean difference of untransformed RT indicated the Stress group was, on average, less than half a second faster with their responses, compared to the Control group (See Figure 6); however, this difference was not significant. An independent-samples t-test was also performed on untransformed RT. Contrary to the result of the Sqrt_RT comparison, the result of this test suggested there was *no* difference between the Stress and Control groups for untransformed responses to the performance stimuli, $t(366) = -1.37$, $p = .17$.

Verbal responses from the participants following completion of the performance task indicated some found the task difficult, while others found it easy. These responses did not appear to vary according to which group the participants were assigned to.

This analysis of task performance answered RQ1 and RQ2; specifically, there were no differences in MR task perforamance between the stress and no-stress groups. This finding indicates $H0^1$ should not be rejected.

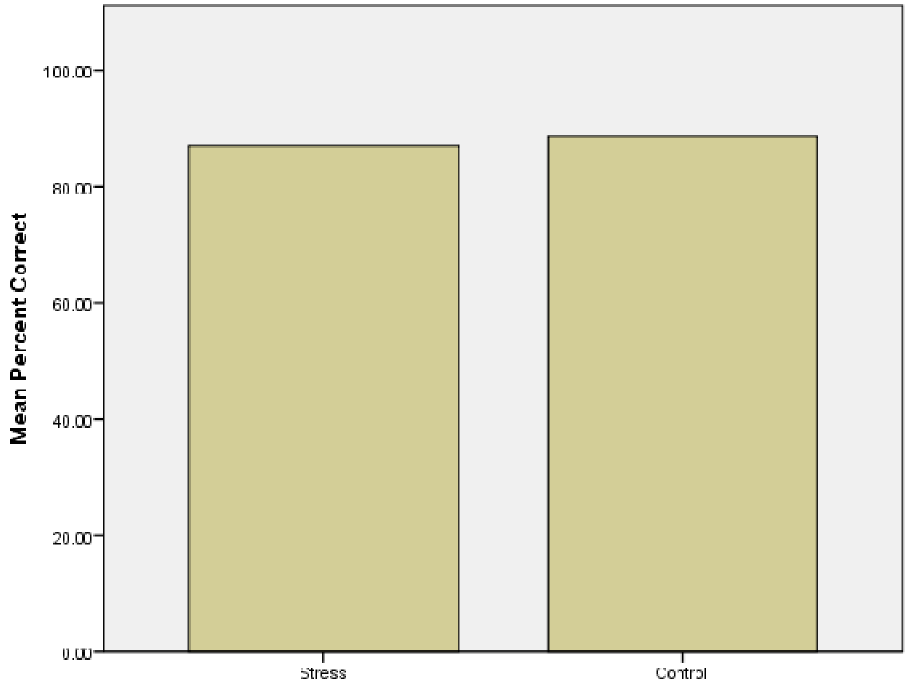


Figure 6. Difference in percent correct (PC) between groups.

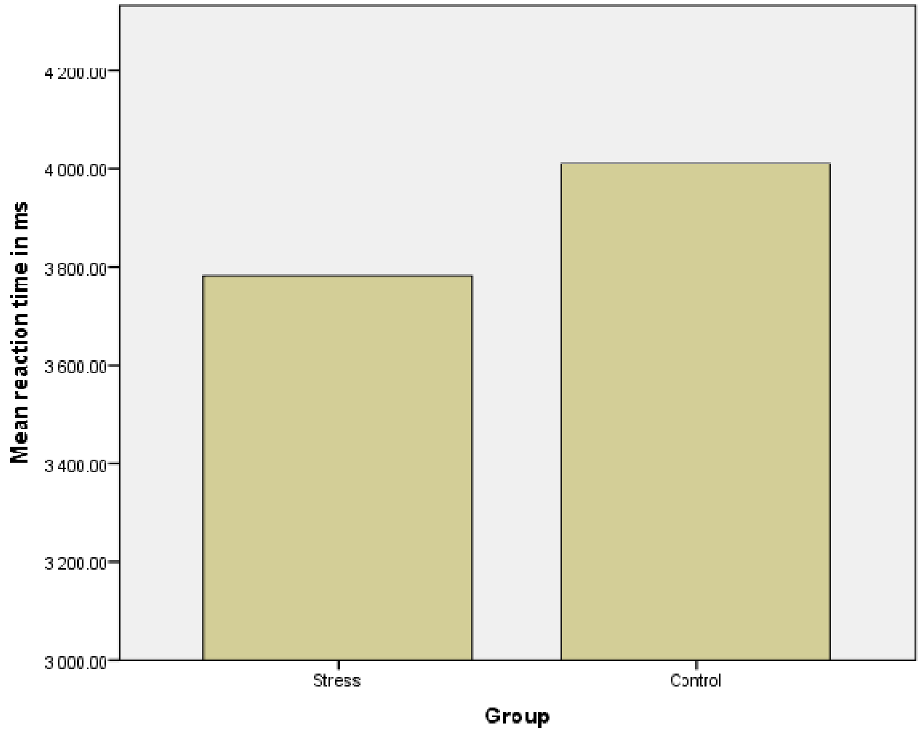


Figure 7. Difference in untransformed reaction time (RT) between groups.

Effects of Angular Orientation

A 2-way repeated measures ANOVA was conducted to examine whether the amount of angular disperity between mental rotation figures in each stimulus pair had any effect on Sqrt_RT, or untransformed RT. The ANOVA compared the two groups (Stress, Control), and five angles of orientation (0, 45, 90, 135, 180). Although there was a visually apparent difference between reactions for the Stress and Control groups, these differences were not statistically significant overall (See Figures 7 and 8).

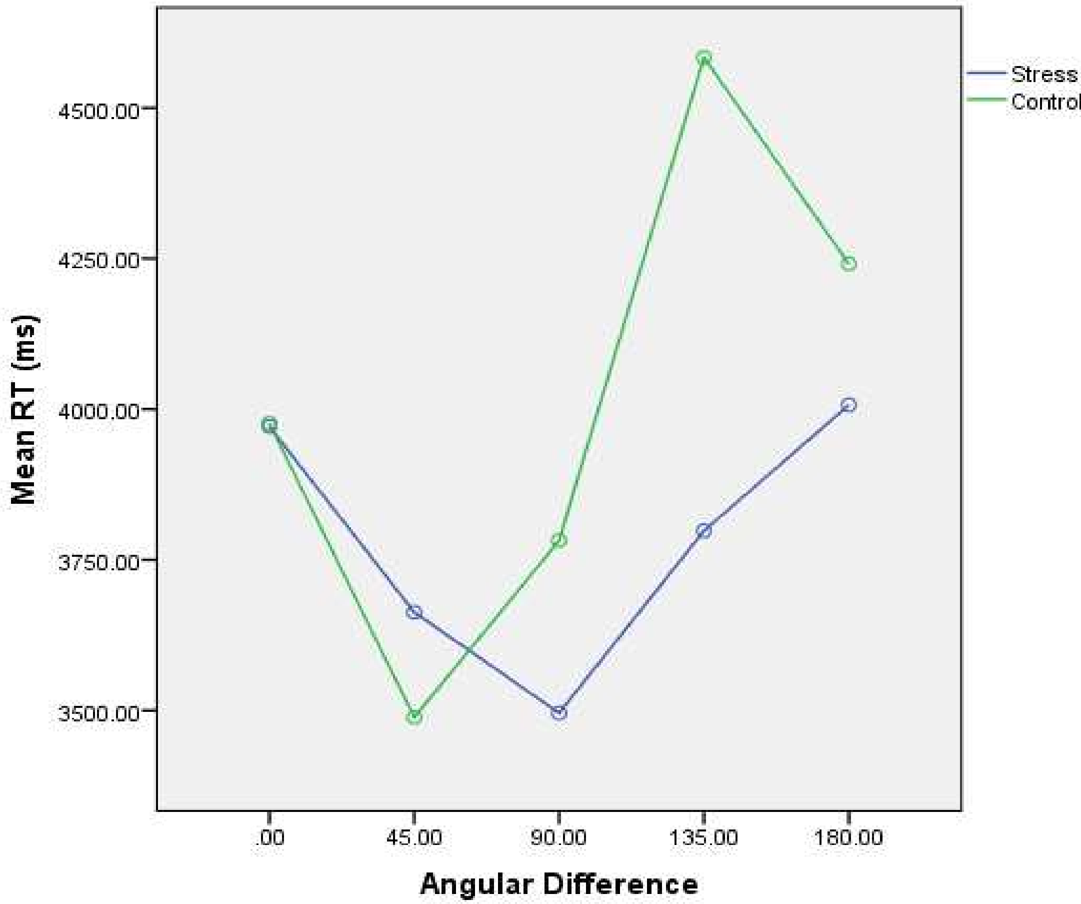


Figure 8. Untransformed RT and angular difference.

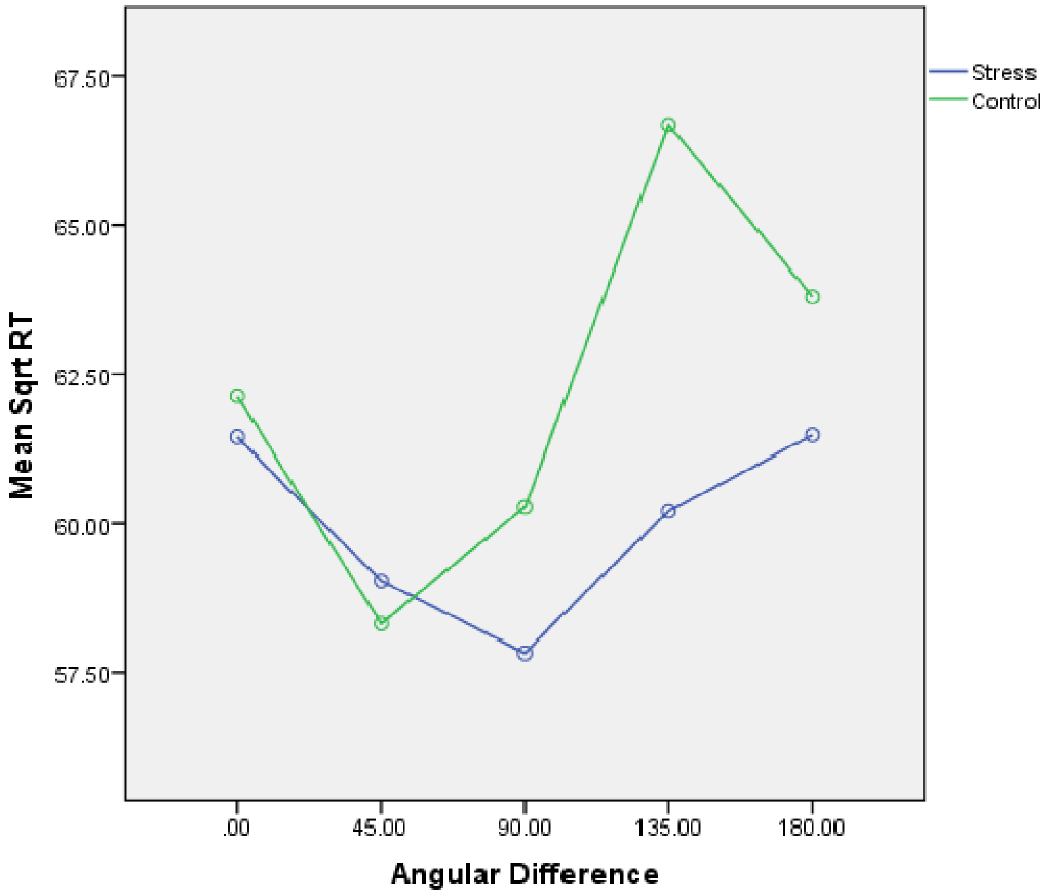


Figure 9. Sqrt_RT and angular difference.

The main effect for group was not significant, F(1,4) = 1.87, p = .17. Likewise, the interaction between group and angle was not sigificant, F(1,4) = .92, p = .46. However, the main effect for angle of orientation on RT approached significance, F(1,4) = 2.26; p = .06. Although there were no differences between groups for how long it took participants to judge angular differences between stimuli pairs, LSD post-hoc analysis of angular difference revealed that for both groups combined, there were significant mean differences in RT when judging angular differences of 45 and 135 degrees (*MD* = 623ms.

p = .02); 45 and 180 degrees (*MD* = 546ms, p = .03); and 90 and 135 degrees (*MD* = 567ms, p = .03).

This analysis of the effect of angular orientation answered RQ3; specifically, the effect of stress was not related to the degree of task difficulty (i.e., angular orientation); both groups took longer to determine the relationship of stimulus pairs when the figures were oriented with increasing angular differences. Therefore, $H0^2$ should not be rejected.

Chapter 5: Discussion

Overview

Mental rotation is the mental manipulation of information held within VSM about an axis of rotation. Mental rotation is essential for everyday tasks, such as finding one's way home from the market, or putting together a jigsaw puzzle, to highly complex tasks, such as landing an airplane at a busy airport (Deyzac et al., 2006; Dror et al., 1993; Hund & Minarik, 2006; Gibb et al., 2008; Millivojevic et al., 2011). While it is widely known that stress can affect performance on many varieties of visual-spatial tasks (Newcomer et al., 1999; Shackman et al., 2006), it is not known what effect, if any, elevated cognitive load has on MR.

Cognitive stress includes cognitively demanding tasks, requiring greater use of cognitive resources, such as attentional processes, memory encoding and retrieval, decision making, and others. Cognitive load is the experience of high demand on cognitive resources (Fitousi & Wenger, 2011), which is a form of cognitive stress. This study sought to shed light on the relationship of cognitive stress to MR performance. This study experimentally examined the effect of mild to moderate stress in the form of artificially elevated cognitive load on MR in normal adults. This study addressed 3 research questions. RQ1 was focused on: Are there differences in MR task performance between the stress and the no-stress groups? RQ2 was focused on: If the answer to RQ1 is ‘yes,’is MR performance improved by the stressor, impaired, or unchanged? Lastly, RQ3 helped me to consider: Is the effect of stress related to the degree of MR task difficulty (i.e., degrees of angular orientation)?

Interpretation of Findings

The Stressor

Because I focused on the effect of stress on a cognitive task, it was essential that the stressor actually be effective at elevating stress. Counting backwards by 7's from 7000 to the pace of an electronic metronome was indeed stressful, as the heart rate results indicated. Heart rate was on average significantly higher in the Stress group after experiencing the counting task, compared to the Control group. This is consistent with the experimenter's observations of the participants while they performed this stressful task, and is consistent with the findings of other researchers who have advocated the use of counting tasks as effective stressors (Camos & Barrouillet, 2004; Ingram et al., 2000; Lagman, 2000; Reisberg, 1983). Participants in this study generally struggled to both count backwards accurately, and to keep in pace with the electronic metronome, which beeped out a relatively challenging pace of 20 beats per minute, or 1 answer every 3 seconds. Indeed, nearly every participant commented to the experimenter after this counting task that the task was difficult and challenging for them.

Research Question 1

Overall, there were no differences in MR task performance between the stress and no-stress groups. However, there were two distinct dependent variables, PC and RT. There was a discernable trend seen for RT relative to the two groups: RT appeared to decrease for the Stress group compared to the Control, however it was not significant. Perhaps this decrease in RT would have been signficant, had there been a larger sample size.

The lack of a difference for PC between groups was unexpected, as many studies have shown that many varieties of stress impact performance, either positively or negatively. Perhaps the lack of a difference in PC between groups is because it may be more important to be fast when performing MR, than accurate. RT exhibited a trend of decreasing for the stress group, but this trend was not significant. This suggests the stressor was *useful*, or provided U-stress, as predicted by the YD Law (Yerkes & Dodson, 1908). It may be that had the sample size been larger, this trend would have reached significance.

The lack of a statistical difference between groups for task performance in this experiment may be due to mathematical averaging of individual differences in how stress is perceived and managed. Although not specifically analyzed for this experiment, it did appear that some individuals were markedly faster and more accurate, compared to others, and within both groups. Indeed, many authors have acknowledged individuals generally differ with regards to how easily stress is registered in the mind and body, how likely individuals are to perceive something as stressful, and how much stress individuals tolerate before reporting something as stressful (Eysenck et al., 2005; Mogg et al., 1994; Moser et al., 2011; Spielberger, 1983).

One surprising finding from this experiment is how the answer to RQ1 was not in line with predominant theory regarding stress and performance. For example, the YD Law predicts task performance for a variety of tasks should improve with mild to moderate stress; albeit, Yerkes and Dodson (1908) did not specifically mention visual-spatial processing. In addition, closer analysis of both the YD Law and Arousal Theory, as they apply to this experiment, suggest that MR may indeed be a special kind of cognitive process. Specifically, if the YD Law is to apply to MR tasks, then performance should be improved by the stressor; however, with the exception of a slight trend towards decreased RT, exposure to the stressor appeared to have little impact on the process of MR, particularly if one considers PC to be just as important as RT, when defining performance. When examined separately, RT performance may be more susceptible to stress as defined by theories such as the YD Law, compared to the relatively more cognitively complex process of mental comparisons and decision making represented by PC.

It is interesting to consider that MR may be special in how it responds to stress. If these results suggest MR is somehow less vulnerable to mild to moderate stress, one has to consider what purpose this would serve. Perhaps this makes more sense from an evolutionary psychology perspective, whereby the need to have MR perform well under stress may have been important for survival. This begs several questions for future research, such as whether MR is affected by higher levels of stress, such as in a survival situation, or while hunting for prey and avoiding predators. How might individual differences in how stress is experienced and processed, as well as differences in experience with MR tasks, play a role in MR task performance?

Other reasons for no difference in MR task performance between groups in this study include the possibility that the performance task was not difficult enough to see a change. Or, perhaps MR is resistant to the effects of stress inherent in hypervigilance tasks. Indeed, the Stress group did evidence significantly higher heart rates, compared to the Control group, indicating the stress experienced is inadequate to affect MR. However, given the observed trend for RT to decrease in the Stress group, the stressor may have been adequate to affect RT, but inadequate to impact cognitive processes such as attention and decision making, as measured by PC.

Research Question 2:

Because the answer to RQ1 was *no*, RQ2 was no longer relevant to this experiment's results.

Research Question 3:

The effect of stress was not related to the degree of angular orientation. Both groups took longer to determine the relationship of stimulus pairs, when the figures were oriented with increasing angular differences; specifically, when figure pairs were oriented from 45 up to 135 degrees of angular difference. This indicates that both groups found stimulus pairs with larger angular differences more difficult than pairs with smaller angular differences, whether exposed to the stressor or not.

RT differences between mirror images and 45 degrees, and mirror images and 180 degrees of angular difference were not significant for either group. This indicates that perhaps it is not the amount of degree difference that is most important, but rather something else about the figure orientation. That is, one might expect that because 180 degrees of difference is the largest possible amount of difference for any two figure pairs in this experiment, both groups would take significantly longer to respond to such figure pairs. However, when one closely examines figures with 180 degrees of angular difference, one figure will appear up, down, left, or right, relative to the other, due to the center block of the modified Shephard-Metzler L-shaped figures used in this experiment. This extra block may have served as a kind of reference point for participants, which if so, may have made it easier to recognize 180 degrees of angular difference in orientation.

Implications for Social Change

Several researchers have shown that even low levels of stress can impair performance on some cognitive tasks (Broadbent, 1978; Luciano et al., 2004); however, apart from an observed trend towards shorter RT for the Stress group, there were no significant differences between groups for MR performance. Nevertheless, the results still have implications for social change. According to this study's findings, individuals can tolerate mild to moderate forms of cognitive stress and suffer little or no decreases in MR performance. These results will help employers better understand the effects of stress on tasks that require high degrees of MR, such as aircraft pilot, air traffic controller, search and rescue crewman, and others.

In addition, aviation authorities may not need to be concerned so much with the effects of mild to moderate elevated cognitive load on the process of MR as it relates to spatial awareness and controlling an aircraft. Air traffic controllers could be relatively confident their MR ability should perform no differently with mild to moderate stress, as it does without stress. Search and rescue air crewmen could also worry less about the effects of mild to moderate stress, and focus more on the task of scanning for survivors.

Practically speaking, this study showed that successful experimentation on MR using percent correct and reaction time as performance measures does not need to be done in a formal laboratory. This experiment was conducted in a small office, with a small sample size, and with relatively inexpensive equipment. Other experimenters might be encouraged by this, given the difficulty gathering enough participants, affording experiment equipment, and locating a suitable location for a laboratory in which to conduct the experiment. Such encouragement may result in more experimental studies conducted by students of online schools, which would then benefit science and society with their own contributions to social change.

Moreover, the results of this study contribute to the collective body of scientific knowledge. Finding there was no effect of this study's stressor on MR, one could argue, is just as important as finding there was an effect. In addition, the finding of a trend towards decreased RT for the Stress group, even though insignificant, supports the need for future studies with larger sample sizes. Finally, the results of this study will help other scientists continue with similar research, and provide science with new insight into the relationship of mild to moderate stress and MR.

Recommendations for Action

As the results of this study show no differences between groups for MR performance, no major action is recommended. However, further study is recommended. Although this study revealed that for at least a relatively small participant sample, mild to moderate cognitive stress did not significantly affect MR, it is important to note that no participants indicated they were members of stakeholder groups, such as pilots, air traffic controllers, search and rescue team members, or other groups where MR is of particular importance to job or task performance. Public and private agencies, corporations, academic institutions, and researchers interested in the effects of stress on visual-spatial processing should consider sponsoring additional research into the effects of stress on MR of individuals who regularly engage in tasks where MR is a critical cognitive skill for performance success.

Recommendations for Further Study

Methodology

Many researchers have shown that high levels of stress impair performance on a variety of cognitive tasks (e.g., Deyzac et al., 2006; Eysenck & Payne, 2005; Eysenck et al., 2005; Gil et al., 1990; Litz et al., 1996; Newcomer et al., 1999; Oei et al., 2006; Taverniers et al., 2010). Perhaps if higher levels of stress were induced for this study, results would be quite different. Moreover, if several varieties of stress (e.g., physical, psychological, cognitive, and others) were tested in this study, results might also be different.

The nature of the MR performance task was actually in two dimensions, as it was displayed on a two-dimensional computer screen. Perhaps results would have been different if the performance task were in true three-dimensions, with real three-dimensional blocks presented in real space, and not on a computer screen.

In addition, real-world objects, such as furniture, automobiles, airplanes, even people could be used in place of geometric block figures, so as to simulate the mental rotation done in normal everyday life.

A smaller sample size was necessary in this experiment, due to the difficulty recruiting participants for this task, and the excessive amount of time and money it would have taken to gather a sample of 60 participants, as originally intended. As a result of the smaller sample size, the power of this study is relatively weak. In addition, there were not enough participants to allow for comparison of MR task performance as it might relate to other factors, such as age, gender, and occupation. Clearly, future research on stress and MR performance should use a reasonably larger sample size compared to the sample size of only 20 individuals used in this experiment. However, sample size alone may not reveal the true nature of MR performance and stress; individual differences in MR skill should also be considered, as discussed earlier in this chapter. In addition, it might have been useful to include all participants in both groups, so as to more clearly see any effects on performance due to the stressor, and lessen the effect of individual differences.

Equipment

The use of a simple heart rate monitor worn on the wrist as the only means of assessing stressor effectiveness is another limitation, and future research might do well to consider using more sophisticated means of measuring stress. If technical resources permitted, more sensitive measures of physiological correlates of stress might have been used in this experiment, such as galvanic skin response, respiration, and blood pressure. Although the wrist heart rate monitor was able to detect changes in heart rate which provided a sufficient amount of data to compare groups and detect a statistically significant difference in heart rate, the wrist heart rate monitor needed sufficient skin contact, or it would not function properly. Indeed, one participant's HR data could not be used, due to the fact that her wrist was too small to maintain contact with the monitor.

Individual Differences

I observed participants in this experiment to react differently to the figure pairs; some squinted and concentrated intently on the screen, while others showed no facial expression, appearing to find the performance task not particularly challenging. It may be tempting to read into such anecdotal accounts that MR performance may be dependent to some degree on the individual's experience with MR tasks, suggesting that those with more experience should do better than those with less. However, this was not a goal of this study, and data on individual MR experience was not collected. Individual differences in how stress is processed and managed by the participants may have also played a role in MR performance in this experiment, and that such differences might reveal themselves given a larger sample size. Although data on individual differences in stress management was not collected, it is interesting and useful to consider when viewing the results of this experiment. Future research could explore this potential moderator.

Perhaps the lack of a significant difference in performance between groups suggests that MR is both an innate ability, and an ability that can be honed to higher degrees of accuracy. A few participants with occupations and/or experience with tasks requiring frequent use of MR (e.g., students of computer graphic design), performed the best on the experimental task as indicated by having responded faster than all other participants, and having responded 100% correctly. Those with occupations of teacher, nurse, and retiree, showed very similar performance compared to each other, but were not as quick or as accurate as the art and graphic design students. This observation relative to occupation of the participants suggests task performance may be different for individuals whose occupations regularly involve hypervigilance tasks, (e.g., pilots, air traffic controllers, search & rescue air crew). Future research into stress and MR should consider recruiting individuals with such occupations.

Summary and Final Thoughts

MR is a vital visual-spatial process for accurately perceiving our three-dimensional world. As all forms of stress are a common part of our world, it is important to understand how stress relates to VSP in general, and MR in particular. This study showed that the effects of induced cognitive stress in the form of elevated cognitive load did not significantly affect MR. This study did not examine the effects of higher levels of stress, other forms of stress, the duration of the stress on MR performance, or individual differences in how stress is perceived and managed. The sample size was smaller than initially intended, and the participants were a cross-section of the local Savannah, Georgia population; no participants in this study indicated they were pilots, air traffic controllers, or others who might have honed their MR skills as a part of their occupational requirements.

Although this study helped to shed some light onto the relationship of stress to MR, there is much room for further research on the subject. Larger participant samples are needed. Varied forms and levels of stress need to be examined, whenever possible, so as to better simulate stressful tasks that may place high demands on MR. Individual differences in how stress is processed and tolerated, and differences in levels of participant skill with MR need to be addressed. Only after such studies are conducted will we finally have a more complete and thorough understanding of the relationship of stress to MR.

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Appendix A: Participant Screening Questionnaire

Participant Screening Questionnaire

This questionnaire will be used by the experimenter as a participant selection tool.

Study Title: Effects of Mild to Moderate Stress on Mental Rotation

Experimenter: James F. Bell

Date/Time of Interview: ________________

Participant Name:_______________________

Participant Contact Phone:__________________

Age:_____ Gender:_____ Occupation:___________________

Years of Education:____

Questions:

1. Can you easily use a computer mouse and keyboard? Y/N

2. In your opinion, on a scale of 1 to 7, with 1 being not at all tolerant and 7 being extremely tolerant, how well do you generally tolerate stress? 1 2 3 4 5 6 7

3. When required to perform a task under time pressure (for example, when performing a simple math task with a time limit to complete the problem), on a scale of 1 to 7, how stressed would this likely make you feel? 1 2 3 4 5 6 7

4. In general, how stressed do performance tasks presented on a computer make you feel? 1 2 3 4 5 6 7

5. How stressed would you feel while performing simple computer-presented tasks in an average size office of approximately 150 square feet in size? 1 2 3 4 5 6 7

6. How stressed would having the experimenter in the small office with you while you are performing the task make you feel? 1 2 3 4 5 6 7

7. Can you easily count forward from 1 continuously for at least 3 minutes? Y/N

8. If you had to, can you count backwards from 7000 by 7's, at your own pace? Y/N

9. Do you have 20/20 vision? Y/N When corrected? Y/N

10. In general, do you have difficulty with any of the following?

    Short-term memory (for things that happen 5 minutes or less in the past)? Y/N
    Long-term memory (for things that happen > 5 minutes in the past)? Y/N
    Concentration Y/N Thinking Logically Y/N
    Problem Solving Y/N
    If you answered YES to any of the above, please explain:____

____

____

____

11. Have you now or have you ever had any of the following medical issues?

Cardiovascular Disease	Now/Past
Heart Attack	Now/Past
High Blood Pressure	Now/Past
Stroke	Now/Past
Head Trauma	Now/Past
Eye Trauma	Now/Past
Anxiety Disorder	Now/Past
Depression	Now/Past
Other Mental Health Disorder	Other Neurological Disorder
Specify: ____________	Specify: ___________