The Neurodynamics of Working Memory during a Stress Induced State

by

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Table of Contents

List of Figures

List of Appendices

Abstract

Purpose: Currently the mechanisms the brain uses for various processes are not well understood; the bio-electrical system is complex. There are studies that map brain region activation during various tasks and emotional states. A more in-depth assessment is needed at the bio- and electrical level to better understand the brain's functioning state. The purpose of the current study is to measure the electrical activity of the brain during a working memory task pre- and post-stressor. Alpha and theta frequencies have been previously linked with stress and working memory tasks; for that reason these will be the frequencies focused on during this study.

Method: The data were collected from 23 participants that were recruited from the SONA system at the University of Michigan – Dearborn, and the surrounding Detroit- Metro area in Michigan. Participants were connected to the electroencephalogram (EEG) system using the 10-20 international measurement. Their negative affect (PANAS; Watson, Clark, & Tellegen, 1988), and stress (SRQ; Edwards, Edwards, & Lyvers, 2015) scores were measured after the baseline, after the stressor tasks, and at the end of the study. EEG data was collected during a baseline, a working memory task pre-stressor condition, and a working memory task post-stressor condition. The EEG data was collected and reported as amplitude. The stressor tasks consisted of a modified Stroop task and mental arithmetic task that were timed, and negative feedback was provided.

Results: Results indicated no significant interaction between Time x Location x Band. However, there was marginal significance at the Time x Band interaction level, providing marginal support for the idea that the brain enters different band wave frequencies for different tasks, and while in different emotional states. During each time condition, there was a decrease in alpha compared to the preceding time condition. A further look showed marginal significance at the band level, and found significance at the location level. The analysis on the median reaction time during the pre-modified Sternberg working memory task (pre-MSWM) and post-modified Sternberg working memory task (post-MSWM) conditions was marginally significant. There was a decrease in median reaction during the post-MSWM condition compared to the pre-MSWM condition. Further, there was marginal significance in the alpha amplitude between location Fp1 and Fp2 during the post-MSWM condition. Alpha was highest at location Fp1 during both the pre- and post-MSWM conditions. There was a larger decrease in alpha at location Fp1 compared to location Fp2 during the post-MSWM condition. In addition, alpha asymmetry decreased in the post-MSWM condition compared to the pre-MSWM condition.

Conclusion: There was a decrease in alpha during each time condition compared to the preceding time condition. The alpha asymmetry pattern was consistent with previous studies in individuals with chronic stress. There was as decreased in median reaction time during the post-MSWM condition compared to the pre-MSWM condition, which is inverse of what was expected. This could possibly be explained by the participants reaching a peak performance level on the stress-performance curve, there could have been a practice effect that occurred, or possibly a combination of both. Limits on sample size greatly reduced the power of this study. It would be beneficial to conduct similar studies that could aid in understanding the mechanisms the brain uses during various processes.

Chapter 1

The present study was originally developed to assess the neurodynamic properties of individuals that practice mindfulness meditation during a stress induced state. However, due to the inability to recruit enough mindfulness group participants, this group was dropped and the hypotheses were altered before analyses were performed. The scope of the study was to assess the neurodynamic property differences during a normal working memory condition and a post-stressor working memory condition in an attempt to identify neurophysiological differences as an explanation for the observed benefits in individuals that practice mindfulness. Novelty of the current study is still present as it assesses the neurodynamic properties during working memory and comparing it to pre- and post-stressor conditions.

The term “stress” was first used by Walter Cannon (1932) to describe the physiological response that occurs in the body as a result of a stimulus. Since then, there has been many studies researching how stress effects psychological and physiological processes. Stress has been implicated as a risk factor of various health issues including coronary heart disease (Rozanski, Blumenthal, & Kaplan, 1999), a suppression of the humoral immune response (Cohen, Miller, & Rabin, 2001), insomnia (Morin, Rodrigue, & Ivers, 2003), and memory loss and memory impairment (Kaufman, 2011). Stress is also shown to cause impairment in working memory performance (Schoofs, Wolf, & Smeets, 2009). How stress is presented in neurological functioning is not fully understood.

Working memory (WM) is a cognitive system that is used for the storage, use, and manipulation of information for brief periods of time (Baddeley, 1992). Neuroimaging studies have linked brain activation in the prefrontal cortex with working memory tasks (Cahn & Polich, 2006; Markowitz, Curtis, & Pesaran, 2015; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1997; Wilson, Scalaidhe, & Goldman-Rakic, 1993). However, there is a need of more research into the frequency bands that are used during working memory tasks.

The neurodynamic properties of stress and working memory are not yet fully understood. The purpose of the current study is to look at the neurodynamic properties during a working memory task in individuals while in a stress induced state. A review of the current literature on stress, and working memory is provided.

Stress

The physiological response of stress was first proposed to be only elicited by physical threats because they put the individual in immediate physical danger. However, the negative effects of a prolonged stress response were being exhibited in individuals who were not in constant immediate physical danger, and some individuals who were in constant physical danger did not exhibit the negative effects associated with heavy stress (Lazarus, 1993). This implied that there was another mechanism that was unknown. Lazarus (1966) was one of the earliest individuals to include appraisal and coping as factors in the stress response. Sapolsky (1992) provided support for the stress-appraisal models and found that psychological stressors produce the same physiological response as when one is presented with a physical threat. This accounts for the negative health effects from stress that is found in individuals who were not in physical danger. In the current modern society, the majority of stressors are psychological as most individuals are not in immediate physical danger. Studies have shown that psychological stressors can result from of change in sleeping habits, increased work load, education demand (Ross, Niebling, & Heckert, 1999), job stress, martial stress (Schneidermand, Ironson, & Siegel, 2005), and from other stimuli where the individual perceives he/she cannot adequately handle the stimuli.

Physiological stress response

The physiological stress response starts with a stimulus being presented to the nervous system. The nervous system consists of the central nervous system and the peripheral nervous system. The peripheral nervous system is further divided into the autonomic and somatic nervous systems. Lastly, the somatic nervous system is subdivided into the sympathetic and parasympathetic nervous systems. The central nervous system and the sympathetic nervous system communicate with the endocrine system to produce the hypothalamic-pituitary-adrenocortical (HPA) response and the sympatho-adreno-medullary (SAM) response, respectively (Straub, 2007). Each of these systems is complex so only a brief overview will be provided.

The SAM system is the initial fast acting response that involves the release of epinephrine and norepinephrine to increase physical performance to allow the body to react to a threat. The process is achieved by the hypothalamus releasing corticotrophin-releasing hormone (CRH) signaling the pituitary gland to release adrenocorticotrophic hormone (ACTH) which in turn signals the adrenal medulla to release epinephrine and norepinephrine (Straub, 2007). The epinephrine and norepinephrine prepares the body to react to a threat by increasing blood flow, dilating pupils, increasing blood flow to vital organs, slowing digestion, and other unnecessary systems for the time being until the threat is over.

The HPA system is slower acting and restores the body to homeostasis (Straub, 2007). The process differs slightly from the SAM response. Under the regulation of the central nervous system, the hypothalamus releases CRH to signal the pituitary gland to release ACTH, which in turn signals the adrenal cortex to release corticosteroids. The corticosteroids are released to protect the body and aid in mobilizing energy resources, but if the body is exposed too long they can have negative effects on health (Straub, 2007).

Appraisal-coping model

Lazarus (1966) originally introduced the idea of cognitive appraisal of an external stimuli to determine if it was perceived as a threat. In the original construct of the Transactional Model of Stress, he suggested that we cannot view the external stimuli and the individual's response as separate. Instead, he proposed that the external stimulus and response need to be viewed together as a transactional process. In the Transactional Model of Stress, when an external stimulus is presented the individual makes a primary appraisal. At this moment, the individual is assessing the situation to determine if a threat is present. In the secondary appraisal, the individual is assessing if the skills and resources available are enough to appropriately manage the present situation. After the secondary appraisal, a behavioral response is performed. Upon completion of the behavioral response, a reappraisal of the situation is conducted to determine if an adjustment needs to be performed.

Folkman, Schaefer, and Lazarus (1979) identified five types of coping resources that individuals take into consideration: *utilitarian resources* (money, available materials, and societal status), *health* (energy and morale), *social networks*, *general and specific skills*, and *problem-solving abilities*. One considers resources available for the present situation during the second appraisal stage. If it is judged that the resources and skills available are enough to appropriately manage the situation, then the situation will not be perceived as stressful. However, if it is judged that resources and skills are lacking, the situation will be perceived as stressful and will elicit the stress response.

If a stimulus is determined to be a threat, it does not necessarily mean that the individual will experience a negative form of stress. The stress stimulus can be assessed as a challenge, or a harm-loss. If assessed as a challenge, the individual believes the situation will be difficult, but achievable with some benefit; if assessed as a harm-loss, the individual perceives harm or loss will come as a result of the stimulus (Lazarus, 1966). The determination of benefit(s) or harm-loss of the stimulus can be perceived to occur immediately or likely to come in the future.

Working Memory

Working memory (WM) is a cognitive system that allows for the storage, use, and manipulation of information for a brief period of time for tasks such as language comprehension, learning, and reasoning (Baddeley, 1992). Baddeley and Hitch (1974) proposed their original three component WM model which consisted of the central executive system and two “slave systems”; the *phonological loop* and the *visuospatial sketchpad*. The central executive system’s main function is attention control and information processing. It utilizes the other two “slave systems” to manipulate information. The phonological loop holds verbal and auditory information while the visuospatial sketchpad holds visuospatial information.

When first proposed, each component was believed to be divided into smaller components. Wilson, Scalaidhe, and Goldman-Rakic (1993), provided support for the belief of further division of the visuospatial sketch pad with their findings indicating that there are distinct areas in the prefrontal cortex that are used individually for remembering spatial (where the object is) and non-spatial information (what the object is). Although better than other working memory models, the original three component model still failed to account for data that studies were finding (Baddeley, 2000). To account for the findings that did not fit within the original model, Baddeley (2000) introduced the concept of the *episodic buffer*. The episodic buffer is believed to be limited in the capacity of items able to be held. It is within the episodic buffer that the central executive system can integrate information from long term memory and other types of input from various brain regions.

Neurodynamics of the Brain

To understand how stress affects the brain, one must first understand the normal functioning of stimulus processing. When a stimulus is presented, electrical activity occurs in various regions of the brain. The areas of the brain that have increased activity are the regions that are required to process the stimulus. The brain activity can be reduced to the fundamental unit of a neuron. Neurons are used for communication in both the central nervous system and the peripheral nervous system. The central nervous system is comprised of the neurons in brain and the brainstem; the peripheral nervous system is all the neurons that are outside of the brain and the brainstem.

For a neuron to fire, an action potential needs to occur. Neurons have a resting potential electrical charge of about -70 millivolts (mV). The neuron has two forces acting on it, one producing an excitatory postsynaptic potential (EPSP) and the other producing an inhibitory postsynaptic potential (IPSP). EPSPs produce a positive electrical change in the neuron, depolarizing the cell, moving it towards the threshold. An IPSP produces an increase in the negative electric charge within the cell, hyperpolarizing the cell and moving the neuron farther away from the threshold. For an action potential to occur, the neuron must be depolarized to the threshold of about -55mV, with some variability in neurons (Platkiewicz & Brette, 2010). Once the threshold is met, the neuron will fire producing an action potential. Duffy, Iyer, and Surwillo (1989) identified the action potentials of the neurons as the source of the electrical activity of the brain.

The electrical activity produced by the neurons can be captured and measured using an electroencephalogram (EEG). The EEG is a non-invasive method that captures the electrical activity by placing electrodes on the scalp. This measurement allows for an objective measurement of brain functioning which provides insight to mental processes and systems. The electrical activity is often measured in terms of amplitude (measured in microvolts; μV), magnitude (average amplitude over a period of time), coherence (connectivity between brain regions), and synchrony (neurons firing at the same time).

The electrical activity is classified into bands which is determined by frequency (Hz). Currently in the field, there is no agreed upon classification for the wave bands. The core of the bands are generally similar with the edges of the bands varying from study to study. For this reason, it is important to note the frequency range for the band. I will classify the bands used by many who provide neurofeedback services; delta (0.1-3.9Hz), theta (4-7.9Hz), alpha (8-11.9Hz), beta (12-29.9), and gamma (30Hz +).

The different frequency bands can be observed in brain regions at all times; the frequency band amplitude compared to other frequency band amplitudes at the same electrode location is the relative power of the frequency band. In addition to this method of reporting frequency bands, they are often reported as amplitude, magnitude, and in terms of asymmetry. Amplitude and magnitude reporting is consistent with the terms of which they are measured which were previously discussed. Asymmetry reporting compares the band amplitude between two locations.

Neurodynamics of Stress

Stress is assessed frequently by measuring hormones or with psychological assessment, more studies are needed to look at brain's functioning during stress.

The frontal region of the brain is a key area in emotional regulation (Goodman, Rietschel, Lo, Costanzo, & Hatfield, 2013). There are hemispheric-specific functions during emotional responses. In the frontal lobe, the left region manages arousal and the long occurring stress response, and the right region manages the fight or flight response (Craig, 2005). With the right frontal region (sites Fp2, F4, and F8) being involved in the fight or flight response, this location is more likely to be activated during situational stressors as the fight or flight response is part of the faster acting SAM system during stress. The left frontal region (Fp1, F3, and F7) would then be more active during longer-term stress response as it is constantly managing the stress response.

Alpha asymmetry in the frontal regions is the leading researched hypothesis about how stress appears in the neurodynamic properties of the brain in both the longer-term and situational stress. Peng and colleagues (2013) found that participants that were under high constant stress exhibited a significant difference in alpha relative power between the frontal sites (Fp1, Fp2, Fz) and overall alpha asymmetry between the hemispheres. In this study, there was no trial condition. The EEG activity was collected at a resting state for both groups. The alpha relative power was significant in the left hemisphere of the frontal cortex (site Fp1), meaning that those under high constant stress exhibited increased alpha power in the left frontal cortex as compared to alpha power in the right frontal cortex (site Fp2). Peng and colleagues (2013) also found there was a

significant difference in theta relative power at site Fz; the stress group exhibited an increased theta relative power compared to the control group.

Goodman, Rietschel, Lo, Costanzo, and Hatfield (2013) examined alpha asymmetry of participants under three increasingly stressful conditions while measuring EEG activity, skin conductance, heart rate, and acoustic startle amplitude during a working memory task. The participants were presented with the International Affective Picture System (IAPS) for the first trial. In the third trial, the participants were under the most reported stress with the threat of receiving a shock. The researchers found that participants had a higher emotional regulation under the most stressful condition which was exhibited by increased left frontal activity in the alpha range (8-13 Hz; Goodmand, Rietschel, Lo, Costanzo, & Hatfield, 2013).

Research is lacking in studies that look at situational stress response recorded by EEG in humans. Sullivan (2004) found that the right prefrontal cortex is activated during situational specific stress response in rats. While the situational specific stress response is empirically supported in rats, studies are needed on humans. Most current studies are focused on asymmetrical activation, or brain region specific activation.

Neurodynamics of Working Memory

Prefrontal cortex activity has been linked with working memory processes, such as maintenance, attention demanding tasks, and manipulation of information (Cahn & Polich, 2006; Markowitzm Curtis, & Pesaran, 2015; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1997). Multiple studies have reported an increase in theta amplitude with an increase in working memory demand and mental effort (Gevins, Smith, McEvoy, & Yu, 1997; Onton, Delormer, & Makeig, 2005; Raghavachari et al., 2005). Raghavachari and colleagues (2005) also suggested that theta is used as a gating mechanism during the working memory task. They observed an increase of theta amplitude during the task, and an immediate decline in theta amplitude once the task was completed.

Jensen, Gelfan, Kounios, and Lisman (2002) used a modified Sternberg task to assess alpha activity during working memory load. In addition, in only one subject they examined the frontal theta during working memory. There was an increase in the theta band (5-8 Hz) during the retention phase in the frontal regions and in the alpha band (8-13 Hz) in the frequency range 9-12 Hz in the posterior and bilateral central regions of the brain (Jensen, Gelfan, Kounios, & Lisman, 2002). The alpha band amplitude increase ceased when the probe was presented (Jensen, Gelfan, Kounios, & Lisman, 2002). This indicates that alpha is more prominent when cognitive tasks are not occurring.

Gevins, Smith, McEvoy, and Yu (1997) findings support the findings of Jensen, Gelfan, Kuonios, and Lisman (2002). Gevins and colleagues (1997) found an inverse relationship between alpha and the level of cognitive demand required for task performance. In addition, theta increased as the task difficulty increased, and during practice (Gevins, Smith, McEvoy, & Yu, 1997).

Maurer and colleagues (2015) conducted a study looking at the frequencies used during working memory. In the study, they used a modified version of the Sternberg Task. Their results were consistent with previous findings of an increase in theta over the frontal midline during high working memory load (Gevins, Smith, McEvoy, & Yu, 1997; Maurer et al., 2015; Onton, Delormer, & Makeig, 2005; Raghavachari et al., 2005). With the higher working memory load, the responses were less accurate, as well as an increase in the duration of response time. In addition to the frontal midline theta findings, there was a reduction in the lower alpha band (8-10 Hz) power across all sites during high working memory load (Maurer et al., 2015).

Thus far, stress, the performance during a working memory task, and the neurodynamics of each have been studied individually or in pairs. Currently, there is no reported study that measures them all together in a single study- to the researcher’s knowledge. Stress impairs working memory performance (Schoofs, Wolf, & Smeets, 2009) and is displayed as alpha asymmetry in the frontal region (Goodmand, Rietschel, Lo, Costanzo, & Hatfield, 2013; Peng et al., 2013). The theta band increases during working memory tasks (Onton, Delormer, & Makeig, 2005; Raghavachari et al., 2005). However, the neurodyanmic properties of working memory have not reported during a stress induced state.

The Present Study

The purpose of the current study is to assess the effects of stress on working memory performance by looking at the neurodynamic properties during a working memory task while in a stress induced state.

Hypotheses

1. Participants will have higher theta during the pre- and post- stressor working memory task compared to the baseline, and will not be different from the post-stressor working memory task in the frontal regions (Fp1, Fp2, and Fz). The theta band increases during working memory tasks (Onton, Delormer, & Makeig, 2005; Raghavachari et al., 2005), which is why theta is expected to increase when participants move from a baseline; the pre- and post-stressor working memory tasks are equivalent in difficulty, thus no difference in cognitive demand is expected.
2. Participants will have a faster median reaction time in the Sternberg working memory task pre-stressor compared to Sternberg working memory task post-stressor. Stress impairs working memory performance (Schoofs, Wolf, & Smeets, 2009), thus after the completion of the stressor tasks, it is expected the participants will require more mental processing time during the Sternberg working memory task with the increased level of stress.

3. For exploratory purposes, it's anticipated that participants will have higher alpha amplitude in site Fp2 compared to site Fp1 during the post-stressor Sternberg working memory task. Alpha asymmetry, with increased alpha in location Fp1 compared to location Fp2, is present in individuals with chronic stress (Peng et al., 2013). Sullivan (2004) found an increase in the right prefrontal cortex in rats as a response to situational stress. The current study is using a situational stressor, and therefore expects the participants to have an alpha asymmetry pattern, higher alpha at location Fp2 compared to location Fp1, that matches the increased prefrontal cortex activity in the rat study.

Chapter II

Method

Procedure

Upon arrival, each participant received a consent form and was provided an opportunity to ask any questions pertaining to the study. Next, participants completed a demographic questionnaire with questions pertaining to age, sex, ethnicity, highest completed education level, and mindfulness experiences. Afterwards, each participant was connected to the iWORX EEG system. In the beginning of each session, a baseline was collected for ten minutes; the first five minutes was discarded to account for baseline stabilization. During the baseline collection, the participants were looking at a blank white screen. Upon the completion of the baseline, they were given the stress rating questionnaire (SRQ; Edwards, Edwards, & Lyvers, 2015) and the positive and negative affect schedule (PANAS; Watson, Clark, & Tellegen, 1988). Upon completion of the questionnaires, the modified Sternberg working memory task began. Afterwards, each participant was administered the modified Stroop task, and timed mental arithmetic task to induce stress. Immediately after, each participant was given the SRQ and PANAS. Following, they were given a second trial of the modified Sternberg working memory task. Following the completion of the second modified Sternberg working memory task, the participants were given the SRQ and PANAS again. Upon completion of the tasks, the participants were cleaned of the EEG gel and were debriefed. For a layout of the study design, see Figure 1.

Participants

All participants were screened for eligibility using the following exclusion criteria: being left handed, a known history of any form of cognitive disabilities, and currently taking any psychiatric medication(s). All groups were recruited from the SONA system at the University of Michigan – Dearborn and the surrounding Detroit- Metro area in Michigan.

All non-student participants were entered into a raffle drawing, which consisted of four drawings for a winning prize of $100. The students from SONA received credit towards their class requirements and were not entered into the raffle for the prize money.

EEG Data Collection

Each participant's data was collected using the iWorx EEG system; the IX-EEG amplifier with a 10-20 Electro-Cap that has Ag/AgCl electrodes at a sampling rate of 256 Hz and an analog pass band of 0.01 to 100 Hz. The sites were referenced to site Cz. A 60Hz notch filter was added to remove the common 60Hz noise present from surrounding electrical activity. The EEG data was cleaned of artifacts and analyzed using Labscribe3 software.

Measures

Demographics. Participants were asked to provide general information regarding their age, ethnicity, sex, and highest level of education completed. Participants were also asked if they practiced mindfulness meditation. These individuals were further asked their duration of experience practicing mindfulness by selecting a duration range (2- 5.9 mos., 6- 11.9 mos., 12- 15.9 mos., & 16 + mos.). This information was gather via paper and pencil.

The Modified Sternberg Working Memory Task. The Sternberg task (Sternberg, 1966) is used to assess the cognitive processes involved in working memory. The task involves the participant being presented with a list of letters to remember. The list commonly contains one to seven letters, but varies by study design. The presentation duration of the list also varies by study. The list presentation period is followed by a buffer or maintenance period. The onset of the task period is initiated with a probe letter which the participant must decide if this probe letter was on the list or not.

In the present study, the working memory task was a modified version of the originally proposed design by Sternberg (1966). This modified Sternberg working memory task will be referred to as MSWM for the remaining of the paper. Each participant was presented with a random series of letters; ranging from three to seven letters displayed simultaneously for a total of 2.5 seconds. The item list length varied from trial to trial. Following the list presentation, a 3.5 second retention stage with a black "plus sign" was displayed in the middle of the screen on a white background to focus the participant's attention. The trial started with a probe item that the individual had to decide if it was on the list or not. To indicate a "yes" response, the participant had to press "z" on the keyboard; to indicate a "no" response the participant had to press "m" on the keyboard. During the task, percent correct and reaction time was measured.

Modified Stroop Stress Task. The Stroop Test (Stroop, 1935) consists of three trials. The participants are instructed to complete each list as fast as possible. In the first trial, the participant is presented a list of words that correspond to the color (i.e. red, blue, green, etc.) the word is in (i.e. "blue" in the color blue, "green" in the color green, etc.). In the second trial, the color of the word is in a different color than what is stated (i.e. "red" is colored blue, "blue" is colored green, etc.). The participants are instructed to say the color of the word, and not the actual word itself. In the third trial, participants are displayed a different set of word and color combinations that is similar to the second trial, but in a different order. However, this time the participants were instructed to state the word instead of the color that is displayed in (i.e. the word “blue” which is colored green, the correct answer would be blue).

In the modified version of the task, the first trial was consistent with the previously described standard version. The list contained twenty-five words, displayed in a five by five grid. The second trial consisted of an equal amount of words, and the presentation was kept consistent with the standard version. However, the second trial was time limited and negative feedback was provided. The limit for the second trial was .8-seconds per word; totaling twenty seconds. The third trial was also consistent with what was described earlier, with the same time limit, and similar negative feedback as in the second trial. The negative feedback was provided at every third or fourth word regardless of actual performance. The feedback stated was, “you will have to hurry up”, “most people are farther along by now”, “you have to get more correct”, “time is almost up, hurry”, and “you have to be more accurate”.

Mental Arithmetic. In this timed mental arithmetic task, the participants were given a set of 15 math problems that were presented in black font on a white background in the middle of the computer screen. Each question was presented individually for seven seconds. The participants were instructed to provide verbal answers to each question. Regardless of actual performance, the participants were provided negative feedback, such as “that is incorrect, you will have to try harder”, “you will need to hurry up”, “most people perform better at this point” and “most people are farther at this point” at every four second mark in every third math problem. If the participant failed to provide an answer, he/she received the feedback of “you must provide an answer to every question.”

Stress rating questionnaire (Edwards, Edwards, & Lyvers, 2015). The SRQ is a short scale that is quick to be completed that measures the self-reported stress to a situational stressor.

It consists of five items: calm to nervous, fearless to fearful, relaxed to anxious, unconcerned to worried, comfortable to tense, that participants rate on a seven-point scale (1=very calm, 2= quite calm, 3=slightly calm, 4= neither calm/nor nervous, 5= slightly nervous, 6= quite nervous, and 7= very nervous). When compared to the longer state-cognitive scale within the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree, French, MacLeod, & Locke, 2008), it showed a significant positive relationship, $r(89) = .48$, $p < .001$. For this purpose, and its brevity, the SRQ was used in the present study.

Positive and negative affect (Watson, Clark, & Tellegen, 1988). The PANAS scale is a 20-item scale that consists of two 10-item subscales that measures positive affect and negative affect. The participant is presented with a word that describes a feeling or emotion, such as “upset”, distressed”, “active”, “attentive”, and “excited”. They are instructed to respond to the word with how they are feeling at the current moment on a five-point scale (1= very slightly or not at all, 2= a little, 3=moderately, 4= quite a bit, and 5=extremely). The positive affect scale, $\alpha = .89$, and the negative affect scale, $\alpha = .85$, were found to be consistent for describing the participants’ feelings at that moment (Watson, Clark, & Tellegen, 1988).

Task Development. Both the Sternberg working memory task and the modified Stroop task were programmed using OpenSesame (Mathôt, Schreij, & Theeuwes, 2012).

Chapter III

Results

A total of 23 participants were collected. One participant's data was removed from all analyses conducted due to the EEG data not being captured. The remaining 22 participants' data were entered into SPSS, cleaned, coded, and used for analysis. The dependent variable, band wave amplitude, was measured in microvolts (μV). At each location measured, other band wave frequencies are present due to the location not fully being in a single band wave frequency. The band wave amplitude reported is the mean microvolts of the band wave at that location.

If enough participants had been collected that practiced mindfulness mediation, a comparison group would have been created for a between-subjects analysis. However, not enough participants were gathered; therefore, this analysis was not conducted. The analyses were conducted including the three mindfulness participants. A separate analysis was conducted excluding the mindfulness participants, the trends and findings were consistent; therefore the analyses conducted including these participants are reported.

Time, Location, and Band

A repeated measures ANOVA with a 3 x 3 x 3 design was conducted to compare band wave amplitudes of alpha, beta, and theta during the baseline, pre-MSWM, and post-MSWM conditions at sites Fp1, Fp2, and Fz. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(35) = 289.88$, $p < .01$; therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .20$). The overall interaction of Time x Location x Band was not significant, $F(1.6, 33.53) = 2.07$, p= ns.

Time x Band. The interactions between individual levels was assessed to see if there was an interaction effect between them. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(9) = 148.697$, $p < .01$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .294$). The Time x Band interaction was marginally significant, $F(1.4, 27.8) = 3.494$, $p < .1$.

As can be seen in Figure 2; during the baseline, alpha amplitude (*M*= 854.946, *SE*= 372.996) and beta amplitude (*M*= 312.697, *SE*= 103.488) were at their highest level. Both alpha (*M*= 590.47, *SE*= 223.894) and beta amplitude (*M*= 229.508, *SE*= 64.693) decreased during the pre-MSWM condition, and slightly increased during the post-MSWM condition- alpha amplitude (*M*= 386.321, *SE*= 137.692), beta amplitude (*M*= 261.885, *SE*= 119.08). This was not seen in the theta band.

During the baseline, theta amplitude (*M*= 39.329, *SE*= 10.831) was at its lowest. During the pre-MSWM condition, theta amplitude increased (*M*= 67.667, *SE*= 67.667) and decreased during the post-MSWM condition (*M*= 41.807, *SE*= 12.173). The increase in theta amplitude from baseline to pre-MSWM condition is consistent with previous findings from Raghavachari and colleagues (2005), and Onton, Delormer, and Makeig (2005). The theta amplitude decrease and beta amplitude increase findings will be further discussed in the discussion section.

Location x Time. At the location x time interaction level, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(9) = 79.219$, $p < .01$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .352$). The Location x Time interaction was not significant, $F(1.4, 29.6) = 2.52$, *p*= ns.

Band. At the individual level of the repeated measures ANOVA; Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(2) = 23.410$, $p < .01$.

therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε= .592). The further analysis found marginal significances at the band level, F(1.184, 24.855)= 3.741, p< .1. Alpha amplitude was highest (M= 610.579, SE= 110.27) followed by beta amplitude (M= 268.03, SD= 91.307), and theta amplitude was lowest (M= 49.601, SE= 9.129).

Location. At the individual level of the repeated measures ANOVA, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, $\chi^2(2) = 29.365$, p< .01. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε= .565). The look at individual levels found a significant difference between locations, F(1.130, 23.733)= 3.4.154, p= .05). Location Fp1 (M= 471.531, SE= 110.270) had a greater mean than both locations Fp2 (M= 158.125, SE= 57.274) and location Fpz (M= 298.554, SD= 143.717). The location difference was not expected and will be elaborated upon in the discussion section.

Reaction Time

A paired-samples t-test was conducted to compare the median reaction time between pre-MSWM and post-MSWM conditions. Reaction times were captured and is reported in milliseconds (ms). There was marginal significance between the pre-MSWM and post-MSWM conditions, t(20)= 1.94, p< .1. However the results were not as expected. The pre-MSWM median reaction time (M= 1,889.4, SD= 2,163.96) was higher than the post-MSWM median reaction time (M= 1,025.3, SD= 217.95); the inverse was expected.

A correlation analysis was conducted to test if a relationship was present between the second and third PANAS and SRQ questionnaires and the median pre- and post-MSWM reaction times. There were no significant correlations between the second and third PANAS scores with pre- or post-MSWM median reaction times. A significant relationship was present between the baseline-SRQ and second-SRQ (post-stressor) scores, r=.482, p= .05, as well as between the second-SRQ and third-SRQ (post-MSWM) scores, r=.756, p<.01, but no significant relationship was present between the baseline-SRQ and third-SRQ scores. There was a significant relationship between the second-SRQ scores and the post-MSWM median reaction time, r=.437, p= .05, but not between the third-SRQ questionnaire and the post-MSWM median reaction time, r=.323, p= ns.

The significant relationship between the second-SRQ scores and the post-MSWM median reaction time, but not between the post-MSWM mediation reaction time and the third-SRQ score possibly explains the decreased median reaction time between the pre-MSWM and post-MSWM. The participants completed the second-SRQ immediately after the stressor tasks, and the third-SRQ questionnaire immediately after the post-MSWM condition. The time between the second-SRQ and third-SRQ is the length of the post-MSWM condition. The participants were experiencing higher levels of stress immediately following the stressor tasks (M= 20.77, SD= 6.63); but by the end of the post-MSWM condition were not experiencing the same level of stress (M= 16.09, SD= 7.08). To test if the decrease in SRQ scores was significant, a paired-sample T-test was conducted. The decrease in SRQ scores was marginally significant, $t(21)$=1.94, p< .1.

It is possible that during the post-MSWM condition, the participants reached a peak performance level on the stress performance curve (for a review refer to Cohen, 1980); thus, dropping their median reaction time. It is also possible that a practice effect occurred, due to the participants completing similar versions of the same task.

Alpha Asymmetry

A repeated measures ANOVA with a 2 x 2 design was conducted to compare the alpha amplitude between sites Fp1 and Fp2 in the pre-MSWM and post-MSWM conditions. The overall interaction of Time x Location was marginally significant, $F(1, 21) = 4.295$, $p < .051$.

As can be seen in Figure 3; during both conditions, location Fp1 had higher alpha amplitude (pre-MSWM: *M*= 840.118, *SD*= 269.131; post-MSWM: *M*= 559.697, *SD*= 159.358) compared to location Fp2 (pre-MSWM: *M*= 243.06, *SD*= 113.733; post-MSWM: *M*= 223.109, *SD*= 108.505). Both locations experienced an apparent decrease in alpha amplitude, however the decrease was larger at location Fp1 in the left prefrontal cortex.

An alpha asymmetry variable was calculated for pre-MSWM and post-MSWM conditions by subtracting Fp2 alpha from Fp1 alpha. A correlation analysis was conducted to test for a relationship between the pre-MSWM alpha asymmetry and pre-MSWM condition median reaction time, the pre-MSWM alpha asymmetry and the pre-PANAS scores, the pre-MSWM alpha asymmetry and the pre-SRQ scores, the post-MSWM alpha asymmetry and the post-MSWM condition median reaction time, the post-MSWM alpha asymmetry and the post-PANAS scores, and between the post-MSWM alpha asymmetry and the post-SRQ scores. No significant correlations were found in the tested relationships.

Chapter IV

Discussion

Understanding the mechanisms the brain uses to process information is important. If researchers and clinicians understand how a normal healthy brain is functioning, then it will be easier to diagnose, and treat abnormalities. Currently, is it known that the brain is a complex bio-electrical processing system. As more advanced technology is developed, the studies conducted will be able to be more precise and insightful about the bio-electrical system.

It was expected that participants would have higher theta amplitude in the pre- and post-MSWM condition compared to the baseline, and there would not be a difference compared to the post-MSWM condition. Due to previous findings of theta increasing as cognitive demand and working memory load increases, and there being no difference in cognitive demand between the pre- and post-MSWM conditions. It was also expected that participants would have an increased median reaction time in the post-MSWM condition compared to the pre-MSWM condition. The increase in median reaction time would correlate with the post- and post2-SRQ scores and thus reflect the participant requiring more mental processing time during increased level of stress. Finally, it was explored that participants would have higher alpha amplitude at location Fp2 than at location Fp1 in the post-MSWM condition. Individuals that have chronic stress have an increase in alpha asymmetry with alpha higher in the left prefrontal cortex (site Fp1) compared to the right prefrontal cortex (site Fp2; Peng et al., 2013). However, the present study is looking into a situational stressor. A neuroimaging study demonstrated rats having increased right prefrontal cortex activity in a response to a situational stressor (Sullivan, 2004). Therefore, the present study expected a band wave pattern similar to the situational stressor response in rats.

The present study found the pre-MSWM theta amplitude was higher compared to the baseline condition, and lower when compared to the post-MSWM condition; partially supporting the current study's hypothesis. The increase in the mean theta amplitude from baseline to pre-MSWM conditions was expected, but the decrease from pre-MSWM to post-MSWM conditions was not. It was observed that mean beta amplitude increased from pre-MSWM to post-MSWM conditions. This inverse pattern of theta explains the drop in theta amplitude post stressor tasks. The brain was functioning more in the beta band frequency range than the theta band frequency at the locations tested. There could be a theta/beta relationship during working memory, or during certain levels of stress while conducting a working memory task. The beta and theta relationship during stress and working memory tasks should be further studied.

It was expected that there would be an increase in median reaction time between pre-MSWM and post-MSWM conditions. This would indicate that the participants required more mental processing time during their increased levels of stress. However, the study found that there was a decrease in the median reaction time. Refer to Figure 1 for the study's timeline; a further analysis found a relationship between the second-SRQ scores (post stressor tasks) and post-MSWM condition, but not between the third-SRQ scores (after the post-MSWM condition) and post-MSWM condition. The participants' scores indicated that they were experiencing higher levels of stress immediately following the stressor tasks compared to the third-SRQ scores. The time between the second-SRQ and third-SRQ is the duration of the post-MSWM condition.

Since there was a significant correlation between the second-SRQ score and post-MSWM condition, but not between the post-MSWM condition and the third-SRQ scores, and the difference between the second-SRQ scores and third-SRQ scores was marginally significant, the participants could have reached a productive stress level that increased their performance. This would explain the observed decreased in median reaction time from the pre-MSWM condition to the post-MSWM condition.

Another possibility to explain the decrease in median reaction time is the practice effect. The participants completed the working memory task both pre- and post- stressor conditions. Although the lists presented were randomized, the overall structure was consistent during both conditions.

Finally, it was expected participants would have higher alpha amplitude at location Fp2 than at location Fp1 in the post-MSWM condition; this hypothesis was not supported. The present study found that alpha amplitude was higher at location Fp1 compared to location Fp2 during both the pre- and post-MSWM conditions. There was a decrease in alpha at location Fp1 from the pre-MSWM condition compared to the post-MSWM condition. However, it was expected that the alpha amplitude difference would increase from pre-MSWM to post-MSWM conditions, thus increasing the alpha asymmetry. The increase in alpha asymmetry was expected to correlate with an increase in scores on the SRQ and PANAS questionnaires, and an increase in median reaction time; which would provide support for the proposed relationship between alpha asymmetry and situational stress. The alpha asymmetry pattern was consistent with previous findings of alpha being higher in the left prefrontal cortex in individuals that have chronic stress (Goodman, Rietschel, Lo, Costanzo, & Hatfield, 2013; Peng et al., 2013). The interaction at the Location x Time level of the repeated measures ANOVA was not significant, thus no support was found for the Sullivan (2004) finding of increased activity in the right prefrontal cortex compared to the left prefrontal cortex as a response to a situational stressor in rats.

The present study found a significant difference between locations measured; this finding was not expected. Location Fp1 had the highest mean amplitude; it was expected that the locations would be operating at the same levels in each condition until being manipulated. A difference in mean amplitude was only expected during the post-MSWM condition and specifically in the alpha band frequencies. The participants could have been experiencing an emotion or feeling that was not being measured in the current study, which could potentially account for this finding. Future studies should look into hemispheric differences in various mental tasks and states.

Finally, it is important for EEG studies to include a method of artifact rejection. EEGs are highly sensitive to subtle movements; common sources are blinking, eye movements, external electronic sources, and heartbeat. Removing artifacts from EEG data produces a more reliable EEG dataset. Currently, there is no gold standard as the method for EEG artifact rejection.

Future Research

The original study should still be conducted in the future. There is research that needs to be conducted to test for the physiological basis for the observed benefits in individuals that practice mindfulness mediation. A brief overview is provided as support to the purpose of the original study.

Stress impairs working memory performance (Schoofs, Wolf, & Smeets, 2009), and mindfulness reduces perceived stress (Shapiro, Brown, Thoresen, & Plante, 2011). In addition, mindfulness improves attention control and cognitive performance during working memory tasks (Chiesa, Calati, & Serretti, 2011; Moore & Malinowski, 2009; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). During working memory tasks theta increases (Raghavachari et al., 2005; Onton, Delormer, & Makeig, 2005). A study conducted by Dunn, Hartigan, and Mikulas (1999) showed theta to be increased in individuals that practice mindfulness.

Stress, working memory performance, mindfulness, and the neurodynamic properties of each have been studied individually or in pairs, but not all four components together. The original study hypothesized that individuals that practice mindfulness would have higher theta during the pre-MSWM and post-MSWM conditions, they would have a lower median reaction time compared to the control group, they would have lower post-PANAS and post-SRQ scores, and they would have lower alpha asymmetry in the post-MSWM condition compared to the control group. In addition, it was hypothesized that there would be an increase in alpha asymmetry from the pre-MSWM to the post-MSWM condition; specifically with higher alpha at location Fp2.

The original study design would support previous findings in neurodynamic functioning during working memory tasks, would test for a difference between theta amplitude between control group and mindfulness group, would correlate self-reported stress levels with alpha asymmetry, and would test for a difference between the groups on the self-reported stress levels and alpha asymmetry in the post-MSWM condition. The scope of the study was to assess the neurodynamic property differences during a normal working memory condition and a post-stressor working memory condition in an attempt to identify neurophysiological differences as an explanation for the observed benefits in individuals that practice mindfulness.

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Figures

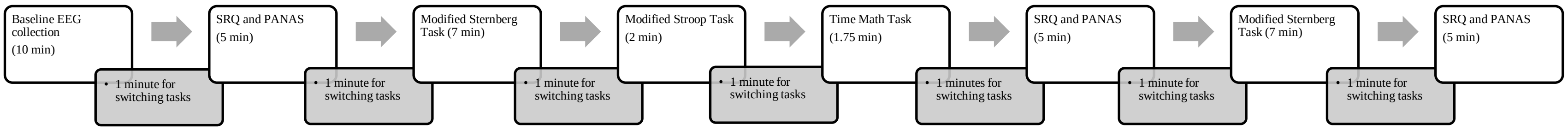

Figure 1. Study Timeline. Shows the time line for the current experiment design. In addition to the listed times, 15 minutes was calculated for set-up and consent, and 10 minutes for clean-up and debriefing.

Figure 2. Time x Band Interaction. The figure visualizes the band wave amplitude means during each time condition, in chronological order. The alpha amplitude decreases moving from one time condition to the next. Beta amplitude decrease from the baseline to pre-MSWM condition, and slightly increases from the pre-MSWM condition to post-MSWM condition. Theta amplitude does the inverse of beta; theta amplitude increases from baseline to pre-MSWM condition, and decreases from pre-MSWM to post-MSWM condition.

Figure 3. Alpha Asymmetry. The figure visualizes alpha amplitude at locations Fp1 and Fp2 during the pre-MSWM and post-MSWM conditions. The time conditions are displayed in chronological order.

Appendix A

Measures

Demographic Questionnaire

Hello and thank you for participating in this study. Please fill out the questions below about general demographics.

Age: ______________ **Sex**: ______________

Handedness: Left Right Ambidextrous

Ethnicity: Black White Asian Hispanic Pacific Islander

What is the highest level of education you have completed?

1. Some high school 2. High school graduate 3. Some college

4. Trade/technical/vocational training 5. Undergraduate of college 6. Graduate of college

7. Some postgraduate work 8. Post graduate degree

Have you every practiced Mindfulness meditation?

Yes No

If yes, please circle the duration you have practice below:

2- 5.9 mos. 6-11.9 mos. 12-15.9 mos. 16+ mos.

Appendix B

Debriefing Document

Debriefing: Thank you for participating in the study! Your time is greatly appreciated.

All feedback that was given during the two mental functioning tasks (the timed Stroop and timed mental arithmetic) was designed to be negative. It had nothing to do with your actual performance. During this time, the feedback was standardize and said to all participants at the same times. Meaning, every individual in the Stroop task was rushed every third word regardless of performance; as well as, every individual was also rushed in the mental arithmetic at the 4-second mark of every other math problem. The feedback provided was designed make you feel pressured and mildly stressed, again, it did not matter how you were actually performing.

The study is over and we can relax. If you feel still stressed or anxious after participating in our current study please do not hesitate to contact University of Michigan- Dearborn Counseling and Support Services Office at (313) 593-5430 or visiting them on the 2nd floor of the UC at 2157.

If you think of any questions after you leave, please feel free to contact Corey Bryant (248) 410-8613 or email bryantcm@umich.edu. You may also contact Dr. Swift at (313) 593-5610 or email dswift@umich.edu.

A few references to articles relating to current study material are provided below if you wish to look up more on the subject matter.

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