ABSTRACT

Title of Thesis: THE IMMEDIATE EFFECT OF VENTILATORY TRAINING ON HEART RATE VARIABILITY AND BRAIN DYNAMICS, DURING TRAINING AND CHALLENGE

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Through a Guided Ventilatory Maneuver (GVM) can lead to changes in the central and autonomic nervous system. Chronic effects of GVM has been reported in the previous literature to enhance physical and mental health. **Purpose:** To investigate the immediate effects of GVM on cortical activity and cardiovascular activity. **Method:** Twenty healthy participants (age 18-30) were recruited. Eligibility for the study required no experience in any mindfulness training. **Results:** Measures of the study utilized electroencephalography and electrocardiogram to measure cortical and cardiovascular changes. The study provided support for acute effects of GVM on cortical dynamics and heart rate variability. Cortical activity exhibited an increase in cortical relaxation during GVM. And cardiovascular activity exhibited an increase in parasympathetic activity. **Conclusion:** The psychophysiological measures of this study provided evidence for GVM as a relaxation technique. Specifically, during GVM, participant's cortical dynamics reflect an increase in relaxation.

THE IMMEDIATE EFFECT OF VENTILATORY TRAINING ON HEART RATE VARIABILITY AND BRAIN DYNAMICS, DURING TRAINING AND CHALLENGE

by

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Arts
2018

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Chapter 1: Organization and Introduction

This literature review aims to bridge the activity of the nervous system with physiological changes to further our understanding of the mechanism of human self-regulation to improve performance. This research project seeks to examine the immediate effects of slow-paced deep breathing training in brain dynamics and autonomic nervous system regulation. Results of this study could provide critical information for optimizing and enhancing cognitive motor function in human performance.

The following chapters will be an introduction and literature review of psychophysiological concepts. First, theories and framework of human performance in the context of central nervous system activity. Second, changes to the autonomic nervous system in response to the human performance. Third, psychophysiological measures will be introduced and how these measurements reflect human performance. Fourth, heart rate variability biofeedback will be discussed regarding its use as a tool to improve cognitive function and reduction of stress.

Chapter 2: Central Nervous System and Performance

Section 1: Psychomotor Efficiency Hypothesis

Characteristics of a high-level performer stem from more than just physiological abilities but rather efficiency of the central nervous system (CNS). The Psychomotor Efficiency Hypothesis states a decrease in non-essential cortical activities may lead to improved motor output and an increase in performance via reduction of interference within essential central motor processes such as stress (Barratt, 1959). Hatfield and Hillman (2001) theorize that the human brain subscribes to the same principles as those of other biological systems when adapting to environmental or internal challenges. An efficient and refined brain requires fewer cerebral cortical resources for processing (Hatfield, Haufler, Hung, & Spalding, 2004). Lower levels of non-essential neural activation lead to a decrease in neural "noise," allowing for more streamlined communication between different regions of the brain (Deeny, Hillman, Janelle, & Hatfield, 2003).

Previous work has shown an adaptive brain is efficient, overcoming challenges with less effort or lower activity (Babiloni et al., 2010; Del Percio et al., 2008). Another study utilizing The Psychomotor Efficiency Hypothesis examined cortical changes associated with increase task difficulties. As task difficulty increases, an increase in neural effort related to cognitive-motor task demand was observed (Rietschel et al. 2012). Similar to other physiological functions of the body, the brain can become more precise and effective through training (Hatfield & Hillman, 2001).

Based on the psychomotor efficiency hypothesis, there are differences in the brain activity between expert and novice (Hatfield & Hillman, 2001). Haufler et al. (2000) found that during the aiming period, experts exhibited lower cortical activity compared to novice shooters see figure 1. As such, the study supports the psychomotor efficiency hypothesis where task-specific "quieting" in the cortex occurs through learning and experience. Also, reaction time differences between expert and novice table tennis players have shown expert table tennis players to have faster reaction times and sensory processing capabilities (Huang et al., 2004). Overall, the studies mentioned above all provide a clear distinction between novices and experts with experts displaying a refined or "quieted" cortical activation during cognitive-motor tasks.

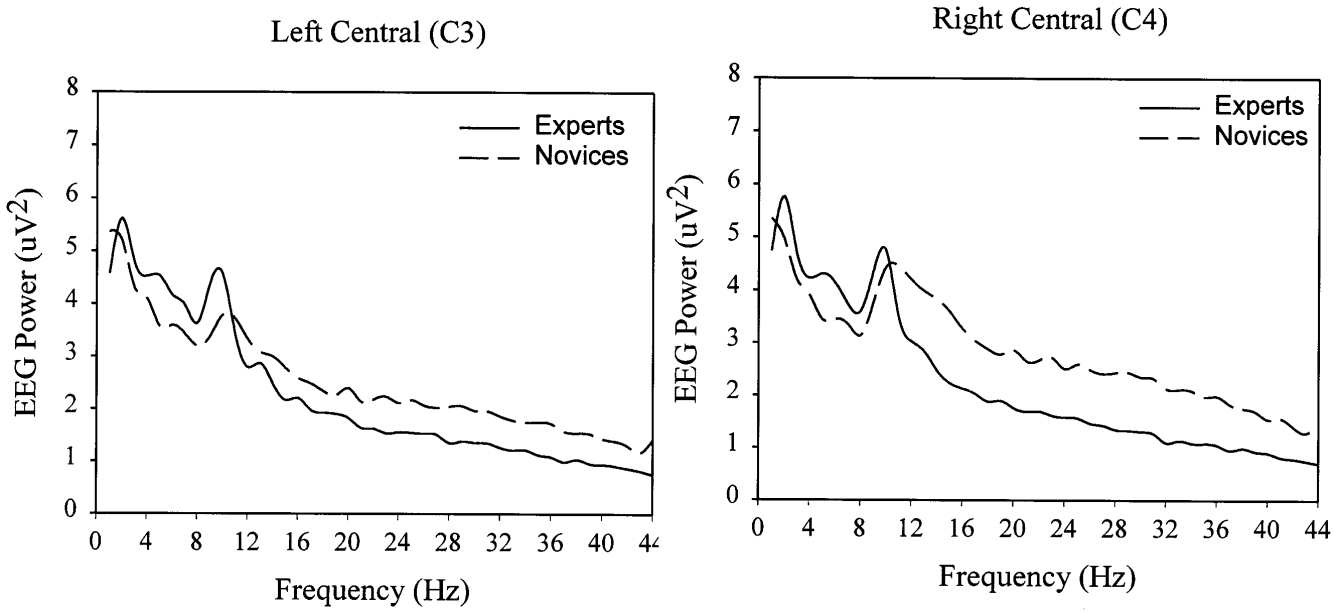


Figure 1. Comparative group spectral plots of the expert and novice target shooters showing relative synchrony of EEG alpha (8 to 13 Hz) (Haufler et al. 2000)

Results from training studies have shown the brain to endure cortical changes over the course of a long-term training period. Kerick et al. (2004) conducted a 12 to

14-week training period to determine the changes in cortical activation of novice pistol shooters. Results of the study found at the end of the training participants improved in shooting percentages. Along with the increase in performance measures, participants exhibited a reduction in cortical activity. Suggesting participants were able to improve and streamline sensorimotor integration after the training period which leads to the reduction in neural activity.

In summary, these studies suggest that enhanced mental efficiency is a critical factor for high-level expert performance via a reduction of non-essential cortical activity. Specifically, regarding cognitive-motor tasks, performance depends primarily on the brains efficiency with the processing of sensory input and motor output.

Section 2: Cognitive Workload Theory

Cognitive load theory (CLT) states performance is determined by how well the brain can allocate attentional resources for cognitive processes (Wickens, 2002; Schmidt & Wrisberg, 2008). Cognitive load is a broad range of cognitive processes such as sensory processing, decision-making, or motor output (Eysenck & Calvo, 1992). Cognitive load refers to the effort in the working memory engagement, emphasis on the limited capabilities of working memory (Sweller, 2011). Working memory is the ability of the brain to process information consciously; it provides temporary storage and manipulation of the information for complex cognitive tasks (Baddeley, 1992, Engle, 2002). Both, cognitive load and working memory, represents the capacity of neural circuitry for processing and information retrieval (Baddeley, 1992). When an individual becomes overwhelmed due to cognitive overload, the

chance for human error and failure increases (Gentili et al., 2014; Miller et al., 2011; Rietschel et al., 2014, 2012; Wickens et al. 1983).

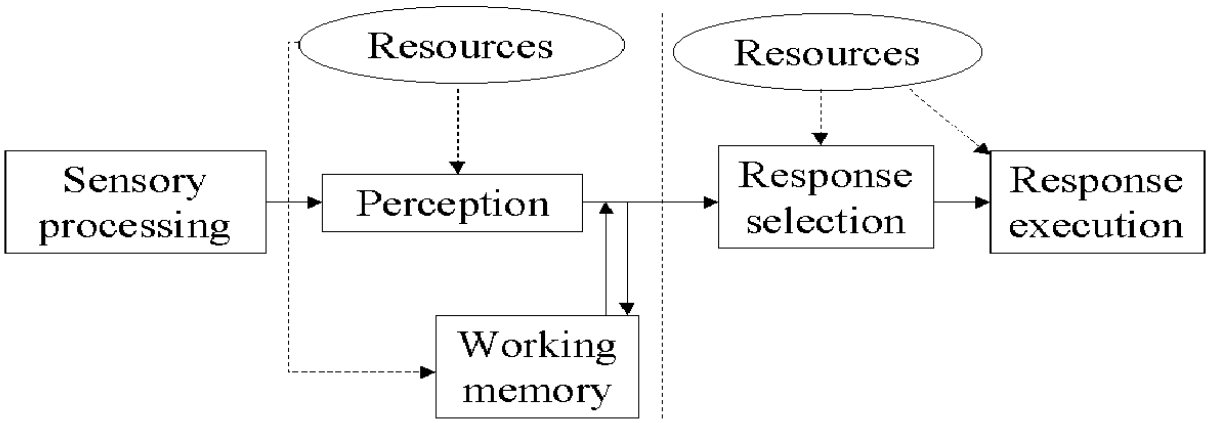


Figure 2. Representation of two resources, supplying the different stages of information processing. Sensory processing, the operation of the peripheral visual and auditory systems, is assumed to be relatively resource-free (Wickens, 2002).

The concept of CLT utilizes a neural economy; although there is no fixed 'cost' for a given task. As the brain becomes more efficient in streamlining attentional resources to appropriate neural centers, the remaining attentional reserve can be allocated for demands beyond those associated with the primary task (Weissman, Roberts, Visscher, & Woldorff, 2006). Thus, as individuals become more skilled at task completion, less attentional resources and therefore additional reserve is available. Psychophysiology investigations of motor performance suggest a refinement in cortical dynamics (Gentili, et al., 2009; Hatfield et al., 2004; Kerick et al., 2004). However, when an individual's attentional resources are depleted, and cognitive workload becomes too high, there will be a decline in their performance and a shift in their physiological state, such as increased sympathetic activity, musculoskeletal response, and neuroendocrine stress patterns (Just, Carpenter, & Miyake., 2003; Hockey, 1997).

CLT stemmed from a framework based on learning. With the limitations of cognitive workload recognized. Therefore, instruction methods needed to be improved to efficiently acquire knowledge and skill application (van Merriëboer & Sweller, 2005). CLT divides cognitive workload into three components: intrinsic, extraneous, and germane (Sweller, 2011). Intrinsic load is determined by the nature of the learning materials and the expertise of the learner. Extraneous load is any additional load applied to the learner which may involve could an overwhelming learning environment or ineffective delivery of the materials due to a poor instructional design by the educator. The germane load is related to how the brain processes and absorbs information, such as construct formation or automation of motor skills. When applied correctly in an educational setting, CLT aims to lower extraneous load to allow additional attentional resources to be directed towards the germane load. The intrinsic load is independent of the learner because it deals with task difficulty and not the cognitive capability of the individual. When assessing human performance from a cognitive-motor perspective, the cognitive workload framework can be applied as well. Intrinsic load accounts for task difficulty, distractors and environmental noise dictate extraneous load and how the brain processes sensory and motor information during decisions demands germane load (Anderson et al., 2011; Paas, Renkle, & Sweller., 2003). The combination of all three loads (intrinsic, extraneous, germane) determines the level of cognitive effort required for task performance.

The concept of CLT relates to how different levels of cognitive load demand different levels of attentional capabilities of the performer. Wickens (2002) divides

the level of demand into two states: (1) when the demand is less than the total resource available to perform the task, resulting in unused resources, and (2) when the demand exceeds the total resource available, causing degradation in performance or crossing the "red-line." When cognitive workload crosses the "red-line," Wickens (2002). Described as a slowing rate or degradation of performance with increases in task demands. Therefore, prolong the duration of being in the "red-zone" can cause performance failure (Grier et al., 2008). In summary, as cognitive load increases and the performer is unable to cope it leads to a rise in mental stress, which results in a decrease in performance.

Chapter 3: Brain and Heart Physiological Circuitry

A topographical network from the CNS governs the ANS. In contrast, to the activation of somatomotor systems, autonomic nervous system (ANS) activity cannot be initiated from cortical structures. However, cortical structures are still involved with ANS response to stress or fear. There are three cortical areas of the brain associated with ANS activity (fig 3): insular cortex, medial prefrontal cortex, and cingulate cortex (Shoemaker, Wong, & Cechetto, 2012). The insular cortex is known as the central command center that ensures heart rate and blood pressure increases during exercise or stress (Nowak, 2005). The medial prefrontal cortex has been shown to influence metabolic activity at rest and recovery (Gusnard, 2001). The cingulate cortex, specifically the anterior cingulate cortex (ACC), detects errors in performance (Carter, 1998).

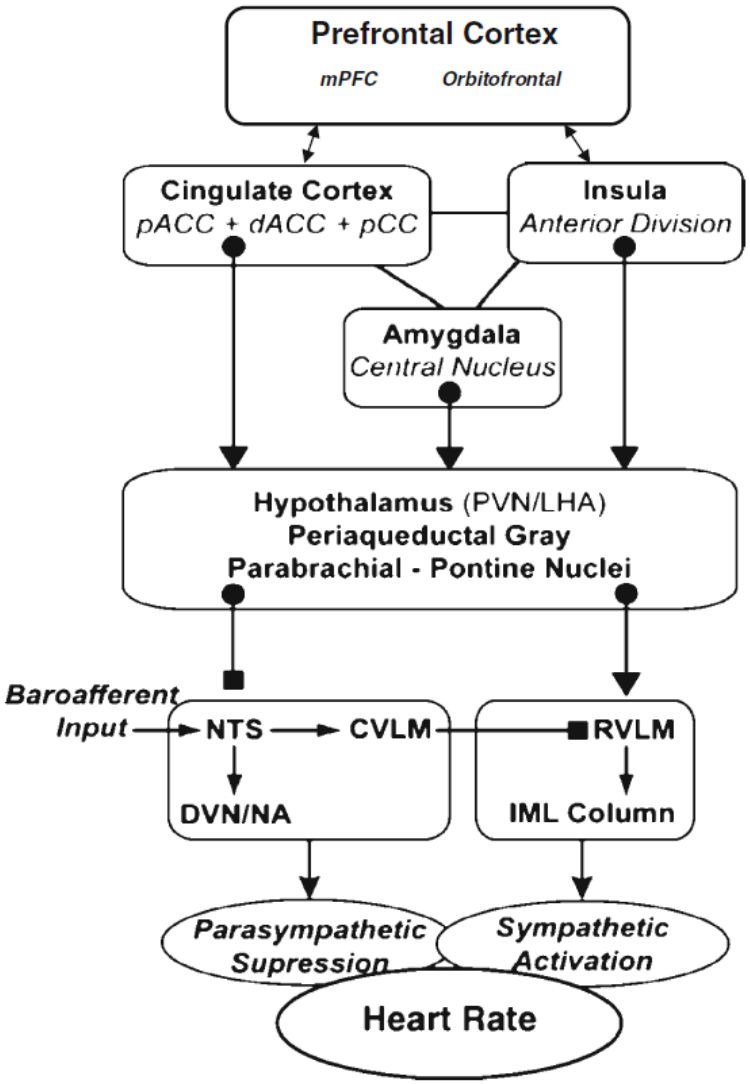


Figure 3. Cortical pathways of autonomic activation (Thayer, 2009)

These three cortical structures, medial prefrontal cortex, insular cortex, and ACC have direct and indirect access to the amygdala. The amygdala relays information from the cortices and communicates the signals downstream to the spinal cord and into the peripheral systems. The amygdalae can impact the motor system, frontal, temporal and parietal cortices within the brain (see figure 4).

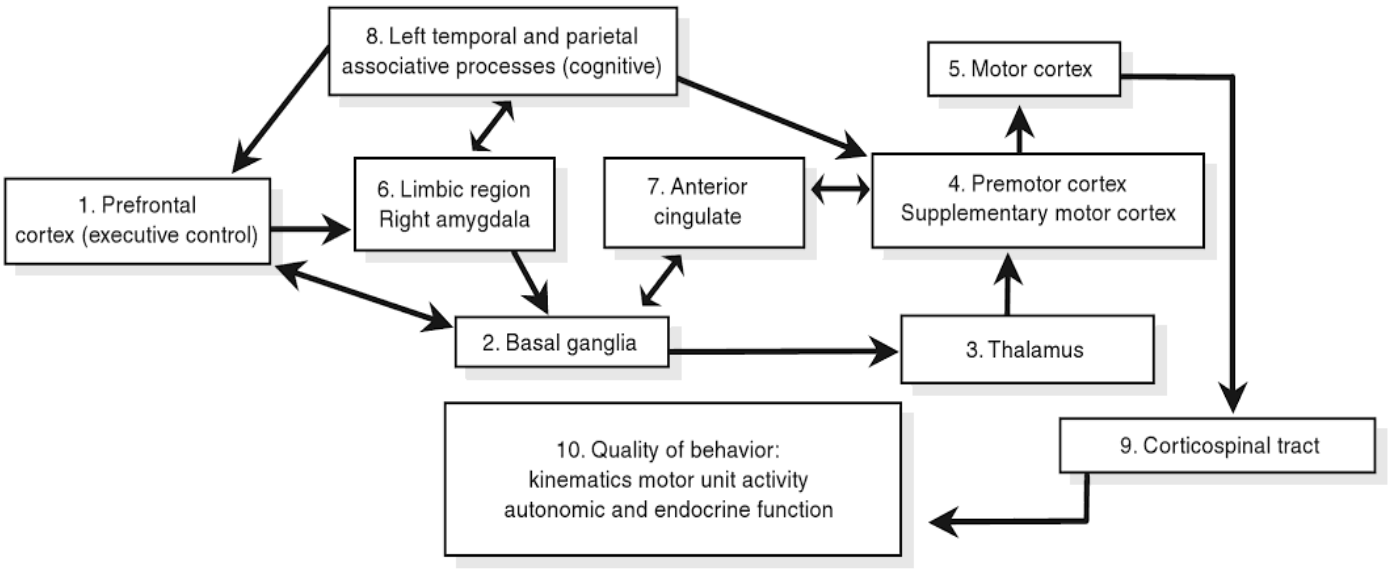


Figure 4. Cortical map of motor planning and output (Hatfield and Kerick, 2007)

The amygdala controls two structures in the brainstem that dictate the activity of sympathetic and parasympathetic response. The first is nucleus tracts solitaries (NTS). When the amygdala inhibits the neurons of the NTS, it leads to the inhibition of nucleus ambiguous (NA) and dorsal vagal motor nucleus (DVLM). This entire process effectively creates a net decrease in the parasympathetic nervous system (PNS) activity (Thayer & Lane, 2009). The second is direct activation of the rostral ventrolateral medulla (RVLM), which results in a net increase in sympathetic activity. These two structures within the brainstem also have their networking with each other. The NTS can inhibit or disinhibit the RVLM through the caudal ventrolateral medulla (fig 3).

The heart acts as the central conductor of rhythmic activity in the body. The neural, hormonal, biophysical, and energy patterns generated by the heart's rhythm provides global synchronization for the human body. The heart's rhythms can facilitate the rapid shift of psychophysiological states, having a strong influence on

the physiological, cognitive and emotional systems (Thayer & Lane, 2009). The heart itself is a neural structure with complex circuitry, allowing it to sense, regulate, and remember. Amour (2003) coined the term “heart brain” suggesting the heart can process information and make decisions about cardiac control independent of the CNS.

Respiratory sinus arrhythmia (RSA) is the synchronization of breathing rate and the cardiac cycle. During inhalation, sensory neurons in the lungs respond to the stretch by increasing its firing rate, leading to an increase in heart rate (McCarty, 2009). The outputs of these sensory neurons travel up to the brain stem and hinder the NTS. This inhibiting of the NTS leads to a suppression of PNS outflow and a net increase in heart rate and SNS activity. During exhalation, as the stretch in the lungs gets reduced, the neurons will decrease their firing rate. Thus, removing the inhibition of the NTS and allowing for PNS rebound (McCarty, 2009). Bilateral direct and indirect connections to this network as seen in figure 3 and 5 draws the link between the CNS and ANS (Thayer & Lane, 2009; McCarthy, 2009). During difficult task performance not only is there refinement and control of the CNS, but also the ANS has a regulatory role on the cardiovascular and muscular system to keep up with the performance demands (Dembowsky and Seller, 1995 Rau and Elbert, 2001).

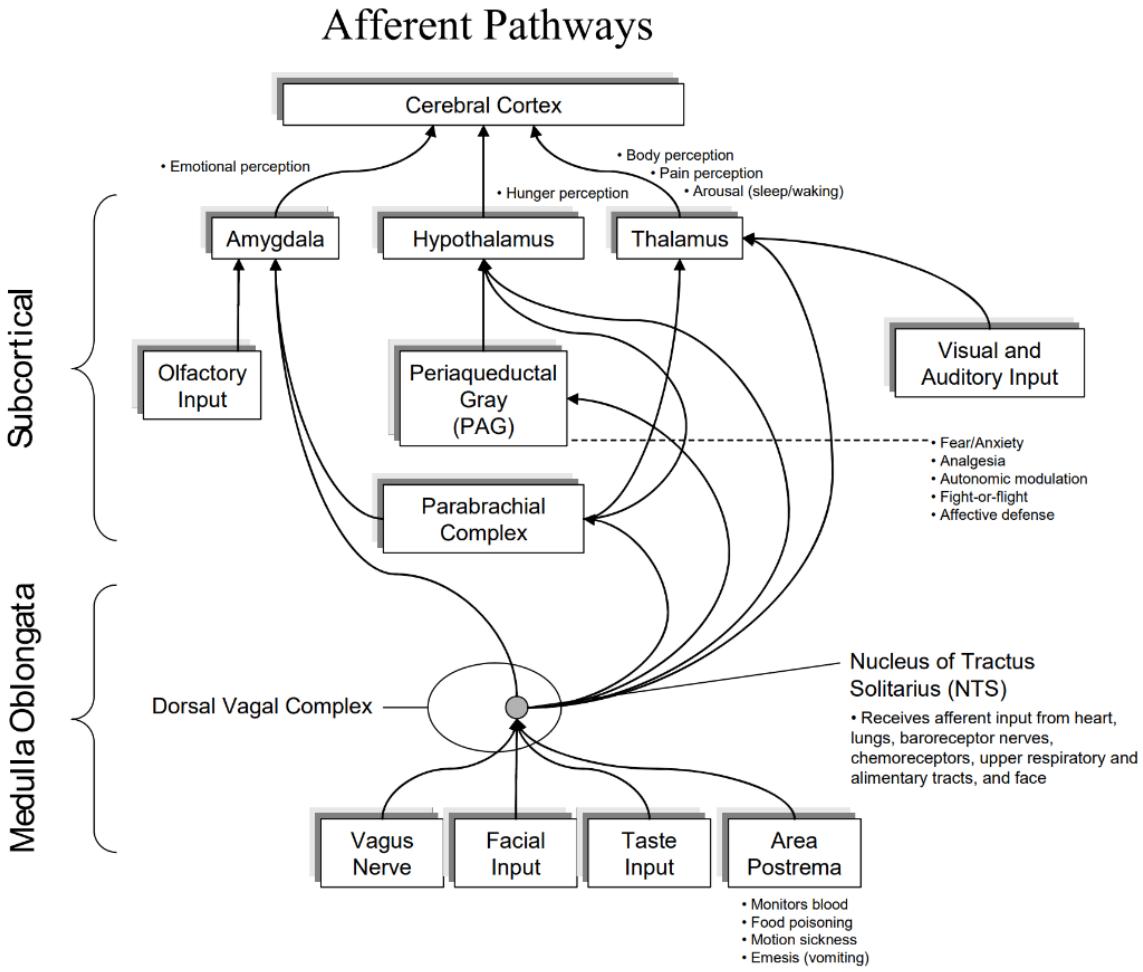


Figure 5. Afferent signal to NTS (McCarty, 2009)

Stress management and emotional regulation largely depend on the ability to adjust physiological arousal on a short basis (Gross, 1998). A flexible ANS allows for quick modulation of physiological and psychological states whereas a rigid ANS will result in the poor ability for one to manage the internal or external changes (Appelhans & Luecken, 2006).

Psychophysiology measures specific physiological variables that reflect behavior, cognition, emotion, and health. Examples include measurements of neural activity,

brain blood flow, HR, HRV, and eye movement (Andreassi, 2010). These measures are noninvasive tools that examine different aspects of the nervous system to bridge the relationship between physiology and psychology (Ganglbauer, Schrammel, Deutsch, & Tscheligi, 2009). In summary, psychophysiology research aims to classify the state of the individual based on the research manipulation and the physiology response towards a stimulus.

Chapter 4: Indexing Psychophysiological Changes

Section 1: Central Nervous System Alpha and Theta Power

Electroencephalography (EEG) is a tool that measures the electrical activity of the brain. The advantage of using EEG is that high sampling rates result in high temporal resolution of brain activity. Thus, EEG can examine changes in brain dynamics during stimuli presentation or task performance. Typical EEG research examines the change in amplitude of neural activity or frequency change within the brain.

Early studies involving EEG suggested that alpha power reflects attentional processes and cognitive performance (Anokhin & Vogel, 1996; Neubauer, Fink, & Schrausser, 2002; Mulholland, 1973; Ray & Cole, 1985). Alpha power is considered the dominant frequency in the human brain (Klimesch, 2012). Alpha power responds to stimuli or task demands by either an increase or decrease in frequency power; alpha power tends to have an inverse relationship with brain activity and attentional focus. As alpha power increases, there is a decrease in arousal and attentional focus, while a decrease in alpha suggests an increase in attentional focus and arousal. Researchers identified two different cognitive processes indexed by the EEG alpha band. Upper-alpha (range of 10-13 Hz) is associated with the processing of sensory-sematic information (Klimesch et al. 1996) while lower-alpha (range of 8-10 Hz) power is associated with arousal-related processes (Klimesch, 1996 & 1997).

Theta band power is another frequency band (range of 4 – 7 Hz) that is associated with neural function and quality of cognitive-motor performance. Frontal theta power has been shown to be related to attentional engagement (Mizuki et al. 1982; Sauseng

et al., 2007). Theta power also has a positive relationship with working memory engagement. Unlike alpha, it has been shown that theta power has a positive correlation with cognitive load and will increase overall as task difficulty increases (Rietschel, 2012; Robert et al. 1984).

Prior studies have reported that during high task load conditions, an increase in theta activity and a decrease in alpha power occurs (Gevins, Smith, McEvoy, & Yu., 1997; Gevins & Smith, 2005; Smith & Gevins. 2005). Other studies have reported a decrease in alpha power during difficult and challenging tasks, suggesting a decrease in alpha is related to attentional focus (Klimesch et al., 1999; Jensen & Tesche, 2002). Furthermore, theta power increase has been shown to be related to cognitive control in suppression task-irrelevant information (Klimesch, 1999; Jensen & Tesche, 2002; Raghavachari et al., 2001). The studies mentioned above support the idea of alpha power being inversely related to cognitive demands, and theta is positively related to cognitive demands.

Alpha power can also be used to quantify the relaxation of the brain. The idea of increased alpha amplitude as reflecting an idling state is supported by findings of increased alpha power when during eyes closed (Barry et al., 2007). Neurofeedback training aimed to enhance resting alpha power has been shown to improve cognitive and psychomotor performance (Ros et al., 2009; Gruzelier et al., 2009; Bazanova et al., 2009). Meditation has also shown an increase in alpha power (Aftanas & Golocheikine, 2001; Kamei et al., 2000; Khare & Nigam, 2000; Litscher, Wenzel, Niederwieser, & Schwarz, 2001). In summary, the increase in resting alpha power reflects a relaxed state and a more efficient brain.

Section 2: Autonomic Nervous System Heart Rate Variability

Physiological measures of peripheral systems can determine the activity of the nervous system. Heart rate variability (HRV), similar to EEG, is a noninvasive electrocardiogram (ECG) measure reflecting the activity of the autonomic nervous system (ANS) (Sztajzel, 2004). Studies have used HRV as a marker for sympathetic and vagal activity. Definition of HRV is the total variation in heart rate or cardiac depolarization (Kleiger, Miller, Bigger, & Moss, 1987).

HRV can be used as a biomarker to measure mental effort. Both in the laboratory and field settings, HRV gives a snapshot of the brain in a nonintrusive measure (Tattersall and Hockey, 1995). In many aviation studies, HRV has been employed as an indicator for task engagement and information processing (Gentili et al., 2014; Kramer, 1991; Sirevaag et al. 1993; Tattersall & Hockey, 1995, Wilson; 1993; Wilson & Eggemeier, 1991). HRV is also sensitive to changes in cognitive workload and can quickly detect a shift between high and low mental efforts (Aasman, Mulder, & Mulder 1987; Kramer, 1991).

HRV indices can be broken down into two frequency components. HRV High Frequency (HF) range from 0.15 - 0.4 Hz in some instances is a measure of PNS activity (Lehrer, 2014; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). HRV Low Frequency (LF), ranges from 0.04 – 0.15 Hz and is more controversial regarding its representation. Early studies have shown that HRV LF is associated with SNS activity (Pagani et al., 1986; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Other studies

have failed to show this association between LF and SNS (Moak et al., 2007; Hopf et al., 1995). Additionally, studies have suggested LF is associated with both SNS and PNS and with baroreflex modulations (Billman, 2011, 2013; Moak et al., 2007; Reyes del Paso et al., 2013). HRV total frequency (TF) power, ranges from 0.04-0.4 Hz and reflects the total variance of HR. High TF suggests a more robust and adaptive ANS (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

HRV has been used to indicate ANS diseases, such as cardiovascular diseases (CVD). Singh et al. (1998) found a decrease in both LF and HF in hypertensive patients compared to healthy individuals. The Framingham Heart Study (1998) found a decrease in LF and HF power associated with all-cause mortality. Liao et al. (1995) found a decrease in LF in older age groups compared to younger age groups. The risk for type II diabetes has been shown with decreased LF (Carnethon et al., 2003). Mental stress symptoms, such as depression and anxiety have been associated with decreases in HF (Kemp et al., 2010; Hassett et al., 2007; Karavidas et al., 2007). Increases in cognitive demand cause an increase in HR and a decrease in HF HRV (Brosschot, Van Dijk, Thayer & Lane, 2007; Pieper, Brosschot, van der, & Thayer, 2007). With HRV measures, complementary information is obtained and provides greater insight into nervous system activity.

Chapter 5: Nervous System Response To Stress

Section 1: Central Nervous System

When examining the effect of mental stress on the central nervous system (CNS), Carmody & Baer (2008) proposed a mediation model on psychological and physiological responses. Within this model, mental stress has a substantial effect on the limbic system. The central component of the limbic system is the amygdalae where multiple sensory pathways converge in the basal lateral nuclei of the amygdalae. This network allows the CNS to immediately process environmental events (Pare, Quirk, & Ledoux, 2004). The amygdalae can impact the motor system, frontal, temporal and parietal cortices within the brain (see figure 4). When an individual becomes overwhelmed by mental stress, there will be a cascading effect on neural efficiency. Stress response by the brain is orchestrated by the limbic system, because of the multiple sensory pathways that converge on the amygdala it relays activity of various cortices (Pare, Quirk, & Ledoux, 2004). Due to this intricate network of the limbic system, the harmful effects of neural "noise" will be amplified and affect other regions of the brain (Hatfield & Kerick, 2007).

Mental stress can influence brain processes and quality of cognitive motor performance. Being able to reduce the "neural noise" of stress experienced by the CNS will ultimately impact the success of task performance. In summary, the study of elite human performance relates to physiology but also the cognitive abilities and control of an individual.

Section 2: Autonomic Nervous System and Mental Stress

Along with neurological changes when performing under challenge, there are also physiological changes within the heart. As cognitive load increases, the autonomic nervous system (ANS) is triggered by suppressing the parasympathetic nervous system (PNS) and elevating the sympathetic nervous system (SNS) (Akselrod, 1981). The body attempts to maintain homeostasis in response to cognitive load increase. This process is known as the 'fight-or-flight' reaction (Van Houdenhove, 2005). As cognitive workload increases, the SNS activity increases as well leading to changes in central nervous system activity along with the physiological process such as cardiovascular, muscular, and endocrine system activity (Mehler, Reimer, & Coughlin, 2012).

The ANS is a collection of motor neurons that regulate heart rate (HR), breathing rate (BR), blood pressure (BP), and other bodily functions (Gabella, 2001). As the name suggests, the ANS is done autonomously without any conscious effort. As the ANS receives information from sensory organs and information from the CNS, it will respond accordingly.

The controls of the ANS within the brain has an intricate connection with the CNS. The link between CNS and ANS is through the limbic system, specifically the amygdala (fig 2). The amygdala receives information from the sensory systems and the prefrontal cortex (Thayer, 2009). The prefrontal cortex controls complex cognitive behavior, such as personality, decision making, emotional regulation, and social behavior (Miller, 2001). Although the motor neurons for ANS output originates

from the brainstem, there is still higher order input from the cortices that will affect the activation of SNS or PNS.

With mental stress impairing cognitive function and contributing to deficits in performance, is the result of a compromised CNS. The second system that becomes compromised due to elevated levels of mental stress is the cardiovascular system. Since the ANS has a direct connection to the heart, this system is susceptible to changes from afferent ANS signals (Saul, 1990). Heart rate (HR) is determined by the joint activity of SNS and PNS with both having direct input to the heart via sinoatrial node. This network of ANS from the brain to the heart is a flexible network that can quickly self-regulate or adapt to environmental or psychological changes (Thayer & Lane, 2007).

Chapter 6: Heart Rate Variability Biofeedback

One technique that has been able to improve cognitive performance and increase stress resilience is the use of Heart Rate Variability Biofeedback (HRVB). This technique aims to bring homeostasis to the body by stimulating the nervous system, respiratory, and cardiovascular reflexes. HRV training teaches individuals to synchronize their breathing to modulate their heart rate (Vaschillo et al., 2006). Such breathing synchronizes an individual's ventilation to a resonant frequency (i.e., six breaths per minute). This synchronization causes Respiratory Sinus Arrhythmia (RSA) which triggers vagal suppression to increase heart rate during inhalation and vagal rebound to decrease heart rate during exhalation (Vaschillo et al., 2006).

There has been an extensive implementation of HRVB as a technique to improve health and cognition. HRVB has found to have a clinically significant impact on cardiovascular disease risk factors, patients who underwent HRVB presented with decrease blood pressure and heart rate in patients with hypertension (Lin et al., 2012). HRVB intervention has also been used on patients with asthma, at the end of the training patients presented with improved respiration and a decrease in asthma onset (Lehrer et al., 2002; Lehrer et al., 2004). HRVB is a treatment tool for individuals who are suffering from mental disorders. Using HRVB as a treatment protocol, patients presented with a decrease in depression scores, mental stress symptoms, and a decrease in state anxiety (Dziemboska et al., 2016; Zucker et al., 2009; Thurber et al., 2010, Caldwell, 2016; Karvidas et al., 2007). Goessl, Curtiss, & Hoffman (2017) conducted a meta-analysis on the effects of HRVB training on stress and anxiety.

Through their analysis, they found that HRVB has a compelling effect size (Hedges g = 0.81) as a treatment tool to decrease depression and anxiety symptoms.

Chapter 7: Effects of HRV Biofeedback on the Cortical Dynamics

Studies utilizing HRVB have found an increase in theta power (Prinsloo et al., 2013), suggesting an increase in internal attention. Correctly, a change in frontal theta, which is common during meditation, was observed (Chan et al. 2008; Lazar et al. 2000). Frontal theta power increase has been associated with activation of PNS (Aftanas and Golocheikine, 2001; Matthews et al., 2004; Takahashi et al., 2005; Lagopoulos et al., 2009). Changes in ANS reflects an increased activity of medial frontal circuitry. The Anterior Cingulate Cortex (ACC) is associated with attentional focus and thus heavily involved in afferent information processing and regulation of autonomic balance (Kubota et al., 2001). These results suggest HRVB, similar to mindfulness training, can trigger a top-down response from the frontal cortex to the limbic system, leading to an increase in PNS activity (Takahashi et al., 2005).

Alpha power increases during states of relaxation. However, studies have found conflicting results on alpha power. Prinsloo et al. (2013) did not find statistically significant improvement in alpha power in HRVB compared to control condition. On the contrary, Sherlin, Muench & Wyckoff (2010) found an increase in alpha power for HRVB participants. In both studies, involved similar populations of untrained novice participants. Sherlin et al. (2010) found an increase in alpha power

in the HRVB condition. The results from Sherlin et al. (2010) denote that individuals do not need to have extensive training for changes in cortical dynamics to occur through HRVB. Dziembowska et al. (2015) utilized a long-term HRVB training on athletes; the training period was three weeks. Results of the study showed that the training group reported feeling less stress and anxiety.

Along with the individual changes participants presented with higher Alpha and Theta power post training compare to the control condition. Another study that utilized a longitudinal study to examine the effects of HRVB training was Rijken et al. (2016). A five-week training period results indicated an increase in alpha power. An additional five-week follow-up observed a further increase in alpha power. The findings of these studies suggest that through HRVB there is a change in arousal for the increase in alpha power to occur.

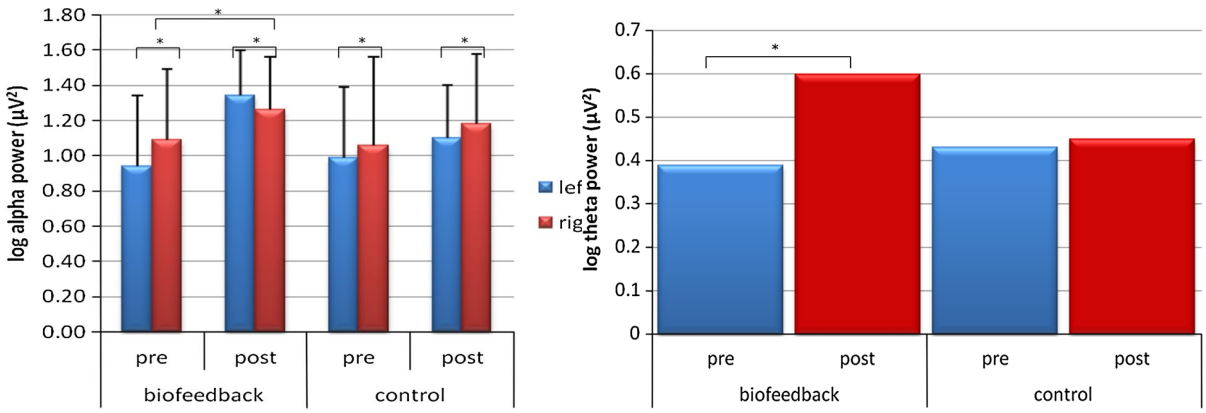


Figure 6. Left: Graphical changes of biofeedback on alpha power in parietal region post HRVB. Right: Graphical changes of biofeedback on theta power post HRVB. (Dziembowska et al., 2016).

Chapter 8: Effects of HRV Biofeedback on Cardiovascular Changes

Through HRVB there is a change or modulation of autonomic outflow from the brainstem. Specifically, studies found an increase in LF and TF power (Prinsloo et al., 2013; Vashcillo, 2002; Lehrer 2003; Song & Lehrer, 2003; Hassett, 2007, Rijken et al., 2016; Sherlin et al., 2010). Song and Lehrer (2003) conducted a study to determine which breathing rate will produce the highest changes in HRV. They had participants breath at a pace of 3,4,6,8,10,12, & 14 breaths per minute. They concluded that breathing at four breaths per minute generated the most power for HRV compare to the other breaths. However, breathing at four breaths per minute lead to an increase in stress. Song and Lehrer (2003) concluded that breathing at that slow of a pace caused an increase in stress rather than providing a calming and relaxing effect. Which they suggest that to gain the benefits of HRVB participants should breathe at a pace of 6 breaths per minute (Song & Lehrer, 2003; Lehrer, 2003). Through the pacing of 6 breaths per minute, leads to a mutual stimulation between RSA and baroreflex. Results of HRVB training has also yielded a decrease in blood pressure, and blood pressure sensitivity (Hassett, 2007). Through repeated training of deep slow pace breathing, an individual's baroreflex becomes more sensitive, resulting in more drastic changes in HR (Sin, 2010). An additional study utilized muscular sympathetic nerve activity (MSNA) as a direct measure of ANS changes while participants underwent HRVB. Results of the experiment found a decrease in

MSNA activity along with an increase in LF (Oneda, 2010) which suggests that HRVB does have the regulatory function of decreasing SNS activity and increase PNS activation.

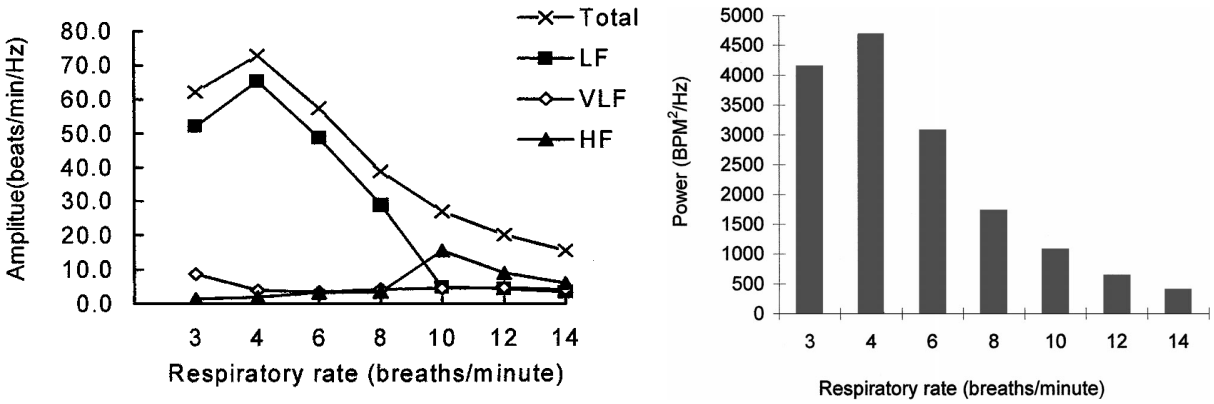


Figure 7. Left: the amplitude of heart rate variability at each respiratory rate. Right: the amplitude of the power peak in heart rate variability at each respiratory rate. (Song & Lehrer, 2003)

Chapter 9: Effects of HRV Biofeedback on Performance

The relationship between anxiety and sports performance is an inverse relationship with each other. As stated previously in The Psychomotor Efficiency Hypothesis, a good performer has a calm and quiet mind. Sports psychologists have utilized HRVB as a tool to assist athletes in quieting their mind. In a study, Strack (2003) assessed performance improvements in high school baseball players who underwent a 6-week HRVB training period. He found a 60% improvement in batting in the training group compared to the control group. Raymond et al. (2005) utilized 10-day HRVB training; they specialized in ballroom dancers. At the end of the 10-day training, participants exhibited an improvement in technique and learning compared to the control group.

Not only has HRVB been beneficial to athletes, but there have also been studies on HRV and its association with increased executive functioning. The findings noted faster reaction times and improvement on correct responses to cognitive tasks (Hansen et al., 2004, Hansen, Johnsen, & Thayer, 2003). Egner and Gruzelier (2004), and Veronon (2003) observed participants showed improved attention and decreased impulsiveness after HRVB training. Prinsloo (2011), observed an improvement in inhibition after HRVB training. McCarty (2002) observed an improvement in cognitive performance and increased reaction time for an auditory discrimination task. In summary, HRVB not only has physical and mental health implications to

improve the state of an individual, but it is also an excellent tool to improve the cognitive function of athletes.

Chapter 10: Research Gap and Specific Aims

Why do some athletes excel under high pressure while other athletes – those equally skilled – fail to perform under elevated levels of physiological arousal and mental task demand? This phenomenon is not exclusive to sports or athletes but includes other high-level performers such as, tactical athletes (i.e., military, firefighter, and police), who also show resilience to cognitive overload when faced with a challenge. Previous studies have recognized that the ability to perform at high levels is not a result of physiological factors alone, preferably, it involves management of the central nervous system (CNS) over the physical resource of the body elevating human performance (Hatfield & Hillman 2001; Janelle, 2000).

The capacity of an individual to perform well can be explained by the psychomotor efficiency hypothesis which describes the superior performance as the result of adaptive neural activation in motor and non-motor areas along with effective networking within the brain. Nonessential cortical activity or neural "noise" can lead to suboptimal neural activation in motor and non-motor regions of the brain, resulting in inferior performance (Hatfield & Hillman, 2001; Hatfield & Kerick, 2007). Excessive neural activity may disrupt the efficient cortical dynamics associated with motor control and result in degraded performance. This change relates to the psychomotor efficiency hypothesis: a decrease in non-essential cortical activities may lead to improved motor output and an increase in performance via reduction of interference within essential central motor processes.

One way to overcome the effects of extraneous increases in neural activity is the use of a slow-paced ventilation breathing technique. Such breathing techniques lower SNS expression, allowing the individual to become more aware of one's psychological and physiological state (Wyner, 2015). Slow-paced and extended tidal volume breathing techniques, such as HRVB, can reduce neural activity (Sherlin et al., 2010).

In recent years, a substantial number of publications have supporting evidence on the positive effects of HRVB. Positive effects of HRVB can lead to a reduction in cardiovascular disease (CVD) risks and utilization for performance enhancement (Gevirtz, 2013). There have been supporting mechanisms of how HRVB improves homeostasis, including improvement baroreceptor sensitivity and increased activity of frontal cortical areas (Vaschillo et al., 2006; Lehrer et al., 2003; Prinsloo et al., 2013). Majority of studies aim to improve health outcome of participants while fewer studies aimed to examine the ability of HRVB to increase performance.

To our knowledge, there have been few studies conducted to examine the acute changes in cerebral-cortical activity when performing a Guided Ventilatory Maneuver (GVM), when individuals breath at a pace of six breaths per. Therefore, this study aimed to examine the immediate effects of GVM on cerebral cortical activity with a focus on spectral band power and Autonomic Nervous System (ANS) regulation. Additionally, to examine if there is an acute effect of GVM as a performance enhancement technique. The results of this study could provide critical information for optimizing and enhancing cognitive motor function in human performance.

To fill the knowledge gaps in the literature, this study aims to address the following research questions. **Primary Question:** Does GVM elicit an immediate effect on cerebral-cortical activity and cardiovascular activity? It is predicted there will be an increase in HRV when participants undergo GVM. It is predicted there will be an increase in alpha power when participants undergo GVM. It is hypothesized that through GVM HRV and alpha power will be positively correlated. **Secondary Question:** Is there an acute effect on GVM to enhance cognitive motor performance? It is hypothesized that through GVM there will lead to an increase in alpha power during the challenge. It is predicted through GVM there will be an improvement in performance during the challenge.

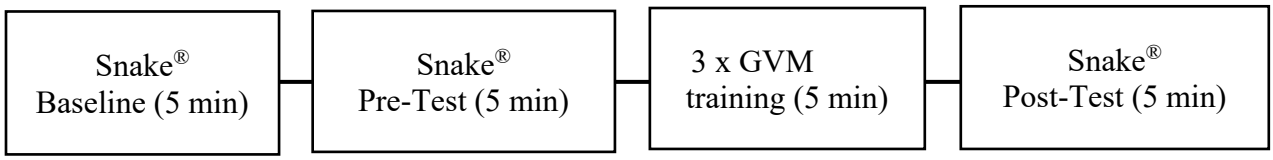
Chapter 11: Methodology

Section 1: IRB Approval

The Institutional Review Board (IRB) of the University of Maryland, College Park had reviewed and approved the study design. IRB approved consent forms were given to each participant before the study to obtain written informed consent from all participants.

Section 2: Study Design

Experimental Condition



Control Condition

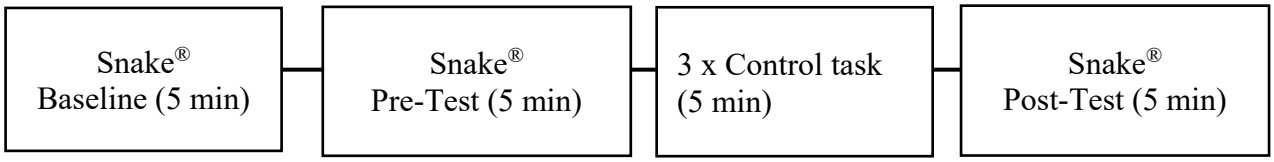


Figure 8. Description of the testing timeline from the start of the experiment to end of the experiment.

Section 3: Participants

Participants for this experiment were recruited from the student population of the University of Maryland, College Park. For this experiment, we collected a total of 20 participants. Criteria for subject recruitment are the age group of 18-30, who are healthy with no prior mindfulness training or biofeedback training.

Section 4: Measurements and Variables

Subsection 1: Electroencephalography

Electroencephalography, or EEG, is a neurophysiological method to record the electrical activity of the brain. It is a non-invasive method utilizing a cap full of electrodes placed along the scalp. The instrument measures voltage fluctuations by the ionic current within neurons of the brain (Niedermeyer, 2005). The first human EEG was recorded in 1924 (Hass, 2003). With the advancement of technology, EEG data is recorded through computer software. EEG has been used in numerous medical settings as a diagnostic tool to examine if the neural oscillations or brain waves differ from the healthy population.

For this experiment, the two main frequency bands of focus were alpha and theta bands. Specifically, it was observed that changes in theta power in the frontal region of the brain are associated with task demand. Both bands are positively related to each other, suggesting there is an increase in working memory and attentional engagement (Jaiswal et al., 2010; Rietschel et al., 2012; Slobounov et al., 2000, 2013).

Subsection 2: Electrocardiogram

The heart has an internal pacemaker called the sinus node. The sinus node regulates HR based on external and internal influence (Van, 1993). Some factors include mental or physiological stress, cardiac or non-cardiac disease, pharmacological treatment, and invasive treatment. Short term HR regulation is governed by sympathetic and parasympathetic neural activity. Factors mentioned above can create a shift of increased activity presented in a parasympathetic or sympathetic response.

Another way to measure the activity of the heart is to examine heart rate variability (HRV) or variation in time-intervals between heartbeats. This variability is the result of interplay relationships between physiological mechanisms that regulate the heart's activity. HRV is calculated from raw electrocardiogram (ECG) signals measuring the distance between R-waves. This measure provides a non-invasive way of assessing cardiac autonomic control and its relationship with the brain (Taelman, 2009). The way to assess ANS dominance on the heart is to examine the power spectral density (PSD) of the peak-to-peak distance of the R wave. PSD of interbeat intervals is focused within three bands of frequency. Low frequency ranges from 0.04 – 0.15 Hz and a high-frequency range from 0.15-0.4 Hz, and total frequency ranges from 0.04 – 0.4 Hz (Akselrod, 1981).

Subsection 3: Behavioral Measures

Participants were seated comfortably facing a 19-inch monitor to play Snake® on two levels of difficulty. Levels of difficulty are defined by the speed of the snake moving on the screen (300ms: easy, 700ms: hard). Furthermore, for a given level of

challenge, the speed of the snake remained constant for the full duration of the task. The participants performed each level of difficulty for 5 minutes. The game automatically restarts when a 'game over' occurs (when the snake hits itself or the wall). The objective of the game for each participant was to stay alive for as long as they could while getting as many points as possible within the five-minute period.

Subsection 4: Subjective Response

The NASA Task Load Index (TLX) consists of six subscales rated on a scale from 0 to 100. These subscales are as follows: mental, physical, temporal demands, frustration, effort, and performance. With combinations of these different domains, the questionnaire hopes to represent workload experience of the individual performing the task (Hart, 2006). The questionnaire gives a subjective measure of cognitive workload and provides a description of the cognitive workload impacts cognitive efficiency (Hart, 1988). The TLX is accurate because the questionnaire scored an $r = 0.80$ for both split-half reliability test and Cronbach's Alpha (Xiao, 2005). A high TLX score indicates a high level of subjective cognitive workload, whereas a low score on the TLX means there is a low level of subjective cognitive workload. Participants will be asked to complete the questionnaire immediately at the end of each trial to get the most accurate snapshot of their subjective workload response to from the task.

Section 5: Data Collection

All data collection was conducted in the Cognitive-Motor Neuroscience Laboratory (room 2303). Upon arrival, participants were asked to complete research consent forms before the initiation of the experiment. After completion of the initial forms, participants were seated in front of a 19-inch computer monitor.

Then, participants then had EEG sensors attached to the scalp. EEG was collected using silver chloride electrodes housed within a stretchable lycra cap, (Electro-Cap International, Inc.). Data was acquired from 26 sites (FZ, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, CP1, CP2, CP5, CP6, T3, T4, Pz, P3, P4, P7, P8, O1, O2, Oz) which are referenced to linked earlobes and a common ground (FPz). Electrode placement was adapted from the 10–20 international system (Jasper, 1958). Electrodes are also placed above and below the right eye over the orbicularis oculi muscle. Additional electrodes are attached to the outer canthi of both eyes to record eye blinks. One electrode was being placed on the chest to record ECG readings. Impedances were below 10 kΩ for electrodes of interest throughout the experiment. All channels were amplified 500 times using Neuroscan Synamps 1, linked to Neuroscan acquisition/edit software (version 4.3). Online bandpass filters were set at 0.01–100 Hz with a sampling rate of 1000 Hz. After electrode impedance has been checked through the brain vision software, two baseline conditions were collected for two minutes of eyes open and eyes closed. Participants were instructed to stay as still as possible, and either looks directly at the blank screen in front of them or have their eyes closed for the whole duration.

After baseline and set up. Scripted prompt of instructions was then given to the participants before the start of the experiment. This allows the same instructions to be given to all participants to avoid any confounding variables due to instructions.

Snake game prompt

> "During this experiment, you will be asked to perform the Snake game at two levels of difficulty. You will start with the easy condition followed by the hard condition. After completing the hard condition, you will be given a rest period, then the hard condition once more. During the Snake game, please do your best to stay alive for as long as you can while getting as many points as possible. When you get a 'game over' prompt after the snake has hit a wall or itself, the game will automatically restart itself. Please continue to play the game as best as you can until the five minutes are up. When the five-minute period is over, you will complete a brief questionnaire asking about how you felt about your performance during the game."

Experimental condition prompt

> "During this rest condition, you will be performing a guided ventilatory maneuver. During the breathing training, please try your best to match the rhythm displayed on the screen. The breathing training will consist of 3 trials; each trial will last for 5 minutes."

Control condition Prompt

> "During this rest period, you will be performing a coloring task. During the coloring, task feel free to color the page however you like. The coloring task will consist of 3 trials; each trial will last for 5 minutes."

Section 6: Data Analysis

Subsection 1: Behavioral Performance and Questionnaires

For each level of difficulty, the performance score of the game was recorded, such as number of game overs, number of actions per game, and the score. Along with performance scores, each participant completed the NASA TLX at the end of each game. The questionnaires are then scored from 0 – 100 based on the participant's response.

Subsection 2: EEG Processing

The EEG signals were digitally low-passed filtered by employing a Butterworth filter (40-Hz cut-off frequency and 48 dB/oct roll-off) with forward and reverse passes for zero phase shift. Then, the EEG time series were segmented in 1-sec non-overlapping windows and with mean baseline-correction using the entire interval. A visual inspection of these epochs was conducted. Any data compromised due to the presence of significant artifacts (e.g., eye-blinks, motor artifact) were excluded from subsequent analyses. The remaining epochs were to be converted to the frequency domain using the Fast Fourier Transform. Then the frequency domains

were independently averaged for each of the two conditions to compute the spectral power for each participant. For every participants' EEG electrode, the average spectral power was computed for the theta (4–7 Hz), low-alpha (7–10 Hz), high-alpha (10–13 Hz), and broadband alpha (7-13 Hz) frequency bands. These averages were natural log transformed for subsequent statistical analyses.

Subsection 3: HRV Processing

The ECG signals were digitally filtered by employing a Butterworth filter (45-Hz cut-off frequency) with forward and reverse passes for zero phase shift. R peak detection using a modified Pan & Tomkins (1985) algorithm was used on the ECG segment in MATLAB. The function uses a threshold detection for R-waves from an ECG signal to calculate the interval distance of the R to R waves. The interbeat intervals or R peaks was then loaded into KUBIOS HRV analyzer to calculate HRV metrics (Tarvainen, 2014). Spectral power of HRV is then calculated into low(0.05-0.15Hz), high (0.15-0.4Hz, and total frequency (0.05-0.4 Hz). The HRV outputs were natural log transformed for subsequent statistical analyses.

Subsection 4: Statistical Analysis

Data were processed using SPSS 16.0.2 (SPSS, Chicago, IL). All variables were assessed for normality, and those identified as nonparametric were log-transformed before statistical testing. All variables were reported as means ± SD. Differences during intervention for EEG was assessed using 2 x 3 x 2 x 5 (CONDITION x TIME x HEMISPHERE x REGION) repeated measures ANOVA. The repeated measures ANOVA indicated a significant interaction effect for CONDITION x REGION, pairwise comparisons were further made. Differences during intervention for HRV

was assessed using 2 x 3 (CONDITION x TRIALS). Differences during intervention for HR was assessed using 2 x 3 (CONDITION x TRIALS). Differences during intervention for BR was assessed using 2 x 3 (CONDITION x TRIALS).

During Challenge EEG was assessed using 2 x 2 x 2 x 5 (CONDITION x TIME x HEMISPHERE x REGION). Statistical significance was set a priori at 0.05, and Bonferroni correction was applied to control for type 1 error associated with multiple testing. For Pre-test post-test changes a 2-way ANOVA (CONDITION x TIME) was used to differentiate in HRV, HR, BR, NASA TLX, and performance measures in both experimental and control conditions.

Chapter 12: Results

Section 1: During Training Results

Subsection 1: Breathing Rate

Repeated-measures ANOVA revealed significant effect for CONDITION x TRIALS for breathing rate F (1,19) = 441.828, p < .000.

Table 1 *Comparison of breathing rate parameters between conditions*

	Mean Breathing Rate				
	Experimental		Control		
	M	SD	M	SD	*p*
Breathing rate	6	0	17.9	2.72	*

*$P < 0.05$

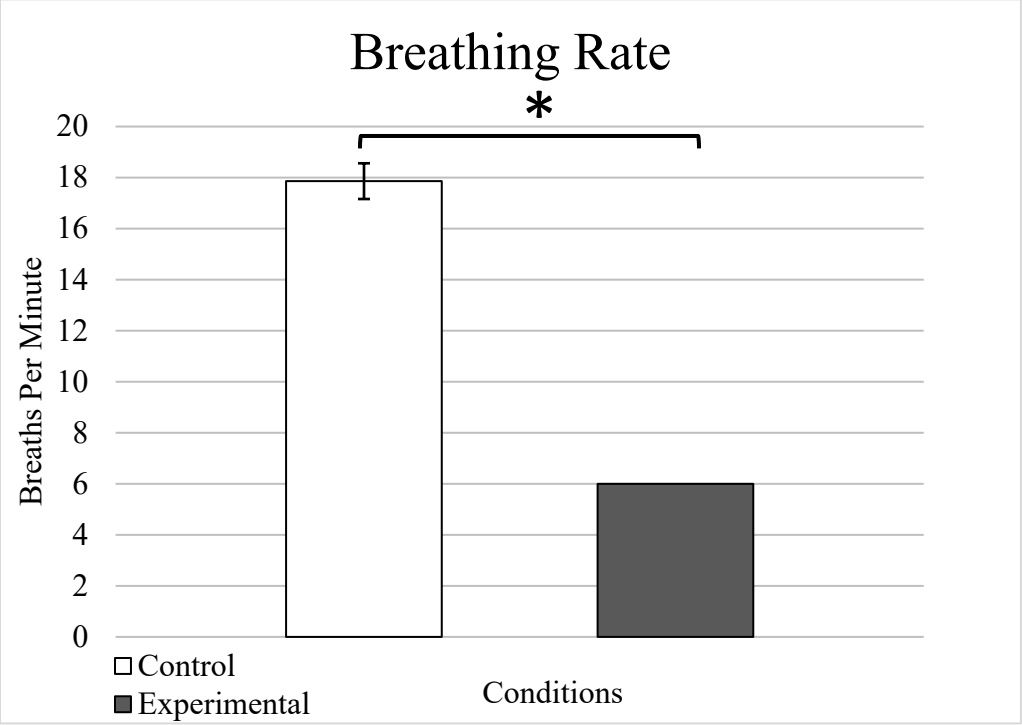


Figure 9. Graphical representation of the effect of breathing rate between conditions (experimental vs. control); error bar plotted with standard error; * $p < 0.05$

Subsection 2: Heart Rate

Repeated-measures ANOVA revealed significant effect for CONDITION x TRIALS for heart rate $F(2, 38) = 4.664$, $p = .027$. There was a significant decrease in heart rate in trial 3 for the experimental condition compared to the control $p = .047$ (Table 2; Fig. 10).

Table 2 *Comparison of HR parameters between conditions*

	Heart Rate				
	Experimental		Control		
	M	SD	M	SD	*p*
Trial 1	71.55	10.11	72.05	10.71	NS
Trial 2	71.4	9.84	72.45	10.76	NS
Trial 3	70.55	9.55	73.15	10.34	*

*$P < 0.05$

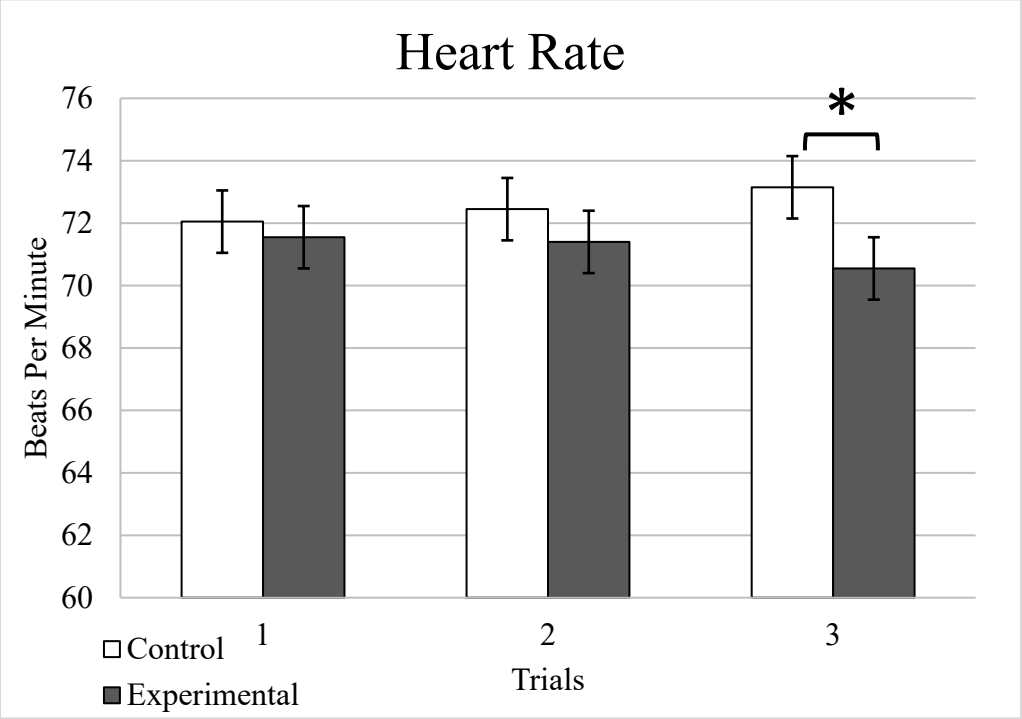


Figure 10. Graphical representation of the effect of heart rate between conditions (experimental vs. control) on trials; error bar plotted with standard error; * $p < 0.05$

Subsection 3: HRV

Repeated-measures ANOVAs revealed significant main effects for the conditions. In the experimental condition significant differences were observed in HRV SDNN, $F(1,19) = 30.004$, $p < 0.001$ HF HRV, $F(1,19) = 18.2$, $p < .000$, LF HRV, $F(1,19) = 126.8$, $p < .000$, and TF HRV, $F(1,19) = 57.6$, $p < .000$ (Table 2).

Table 3 *Comparison of HRV parameters between conditions*

	Power (log (ms^2)				
	Experimental		Control		*p*
	M	SD	M	SD	
SDNN	58.68	19.96	43.13	13.63	*
HF	5.95	0.74	6.55	0.66	*
LF	7.55	0.86	5.57	0.94	*
TF	7.83	0.74	6.93	0.7	*

*$p < 0.05$

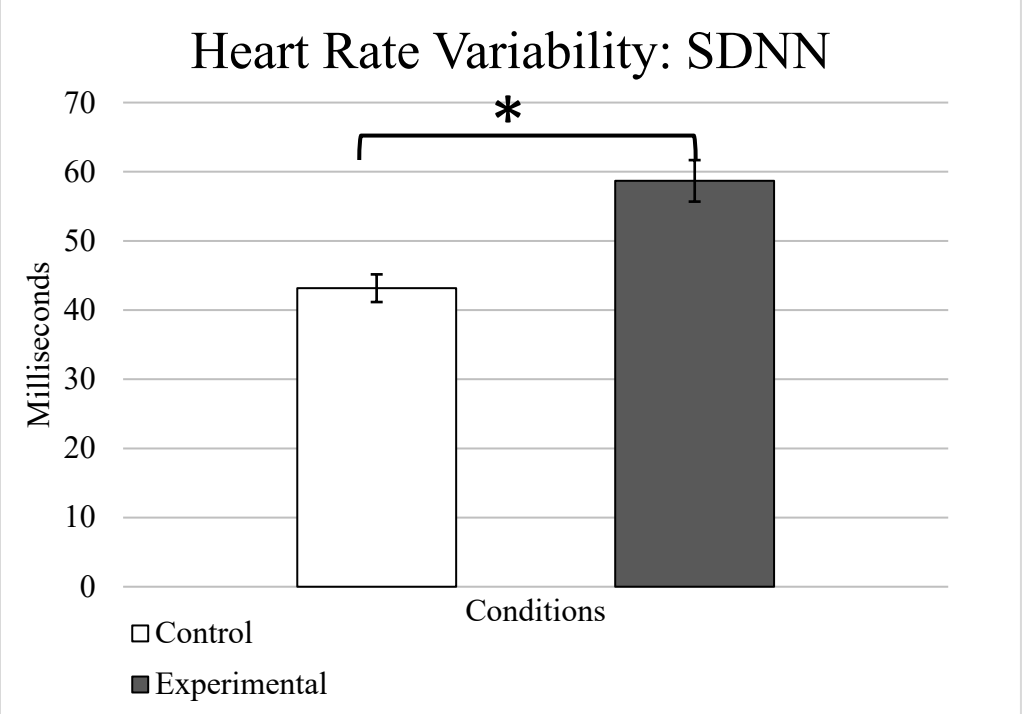


Figure 11. Graphical representation SDNN of HRV between conditions (experimental vs. control); error bar plotted with standard error; * $p < 0.05$

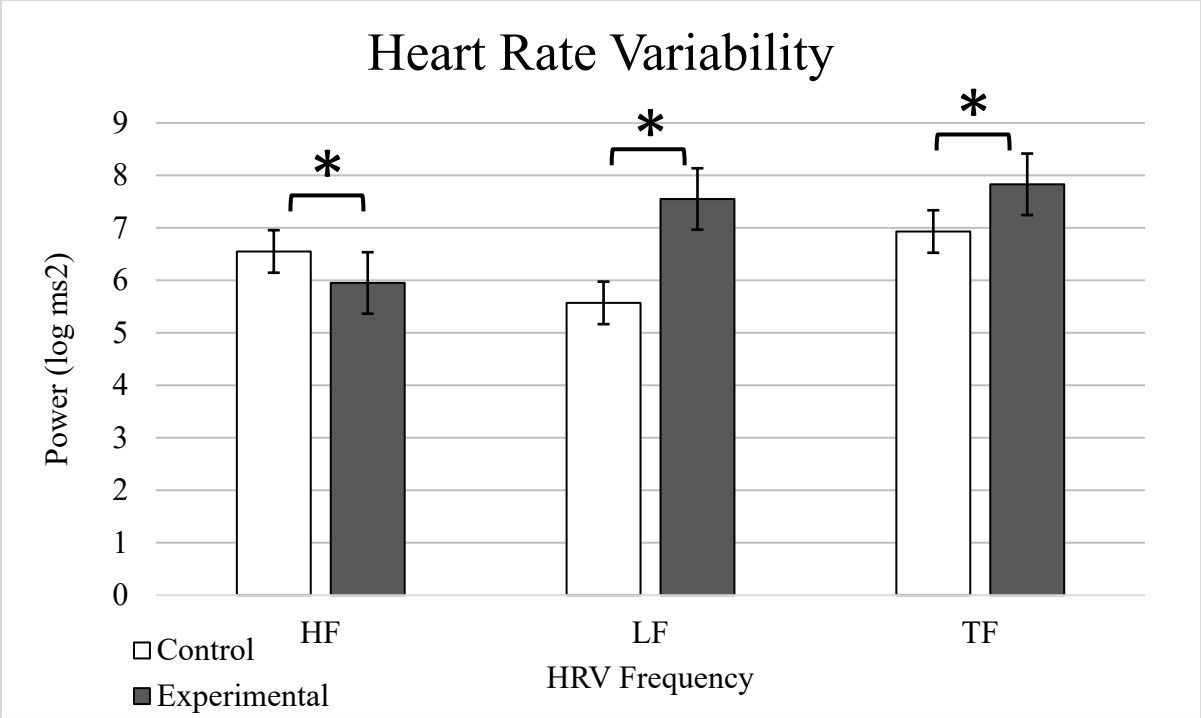


Figure 12. Graphical representation of high frequency (HF) 0.15 – 0.4 Hz, low frequency (LF) 0.04 – 0.15, and total frequency (TF) 0.04 – 0.4 Hz between conditions (experimental vs control); error bar plotted with standard error; * $p < 0.05$

Subsection 4: EEG

Repeated Measures ANOVAs revealed significant main effects for CONDITION x REGION for alpha power (F (4, 76) = 7.942, p = .000), low alpha power (F (4, 76) = 7.552, p = .001), high alpha power (F (4, 76) = 8.051, p = .000). There was a significant increase in all bands of alpha power in the experimental condition compared to the control, specifically the central and parietal regions of the brain (Table 1).

Repeated measured ANOVA revealed significant main effects for CONDITION x REGION for theta power (F (4, 76) = 3.039, p = .038). However, after a post-hoc analysis found no difference in the regions between conditions (Table 1).

Table 4 *Mean Power values in different regions of the brain for biofeedback and control group*

	Power (log μV^2)				
	Experimental		Control		
	M	*SD*	*M*	*SD*	*p*
Alpha					
Frontal	7.8	4.13	7.14	2.83	NS
Central	9.85	4.24	7.45	2.84	*
Temporal	7.01	4.47	5.94	3.18	NS
Parietal	10.11	4.52	8.38	2.41	*
Occipital	9.5	3.97	10.06	2.56	NS
Low Alpha					
Frontal	6.04	4.09	5.59	2.88	NS
Central	7.77	4.03	5.65	2.75	*
Temporal	4.83	3.92	4.07	3.31	NS
Parietal	7.64	3.91	6.54	2.41	*
Occipital	7.26	3.81	8.1	2.48	NS
High Alpha					
Frontal	1.11	4.44	0.26	2.8	NS
Central	3.72	5.25	1.04	3.15	*
Temporal	1.91	4.53	-0.19	3.02	*
Parietal	4.1	4.94	2.13	2.68	*
Occipital	3.73	4.39	4.1	2.91	NS
Theta					
Frontal	2.48	3.41	2.72	2.68	NS
Central	3.42	3.19	2.43	2.55	NS
Temporal	0.41	3.32	0.02	3.14	NS
Parietal	3.02	2.71	2.75	2.06	NS
Occipital	2.62	3.01	3.22	1.93	NS

*$P < 0.05$

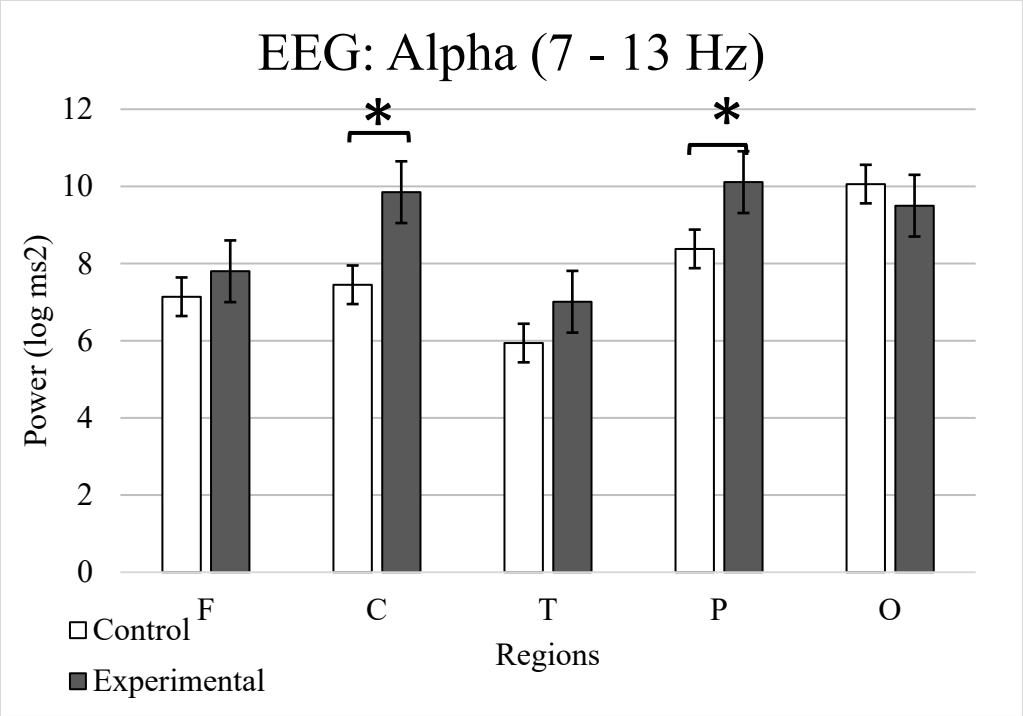


Figure 13. Graphical representation of the effect of alpha power between conditions (experimental vs control) on brain regions; (**F**: frontal, **C**: central, **T**: temporal, **P**: parietal, **O**: occipital); error bar plotted with standard error; * $p < 0.05$

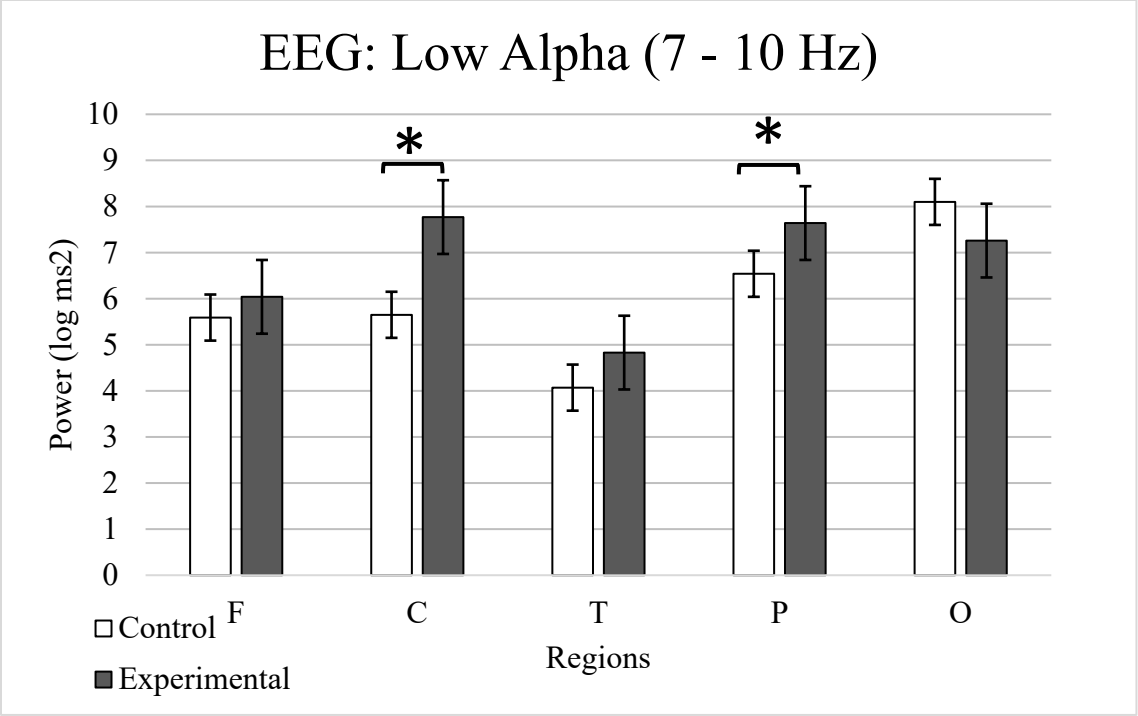


Figure 14. Graphical representation of the effect of low alpha power between conditions (experimental vs control) on brain regions; (**F**: frontal, **C**: central, **T**: temporal, **P**: parietal, **O**: occipital); error bar plotted with standard error; * $p < 0.05$

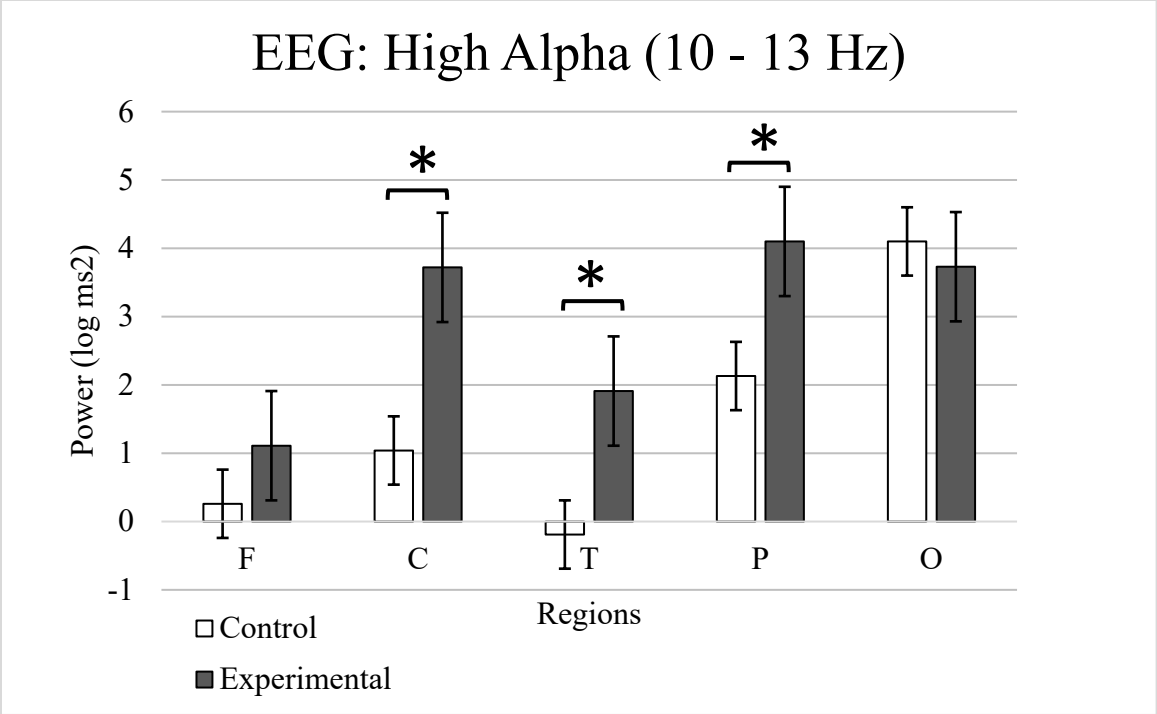


Figure 15. Graphical representation of the effect of high alpha power between conditions (experimental vs control) on brain regions; (**F**: frontal, **C**: central, **T**: temporal, **P**: parietal, **O**: occipital); error bar plotted with standard error; * $p < 0.05$

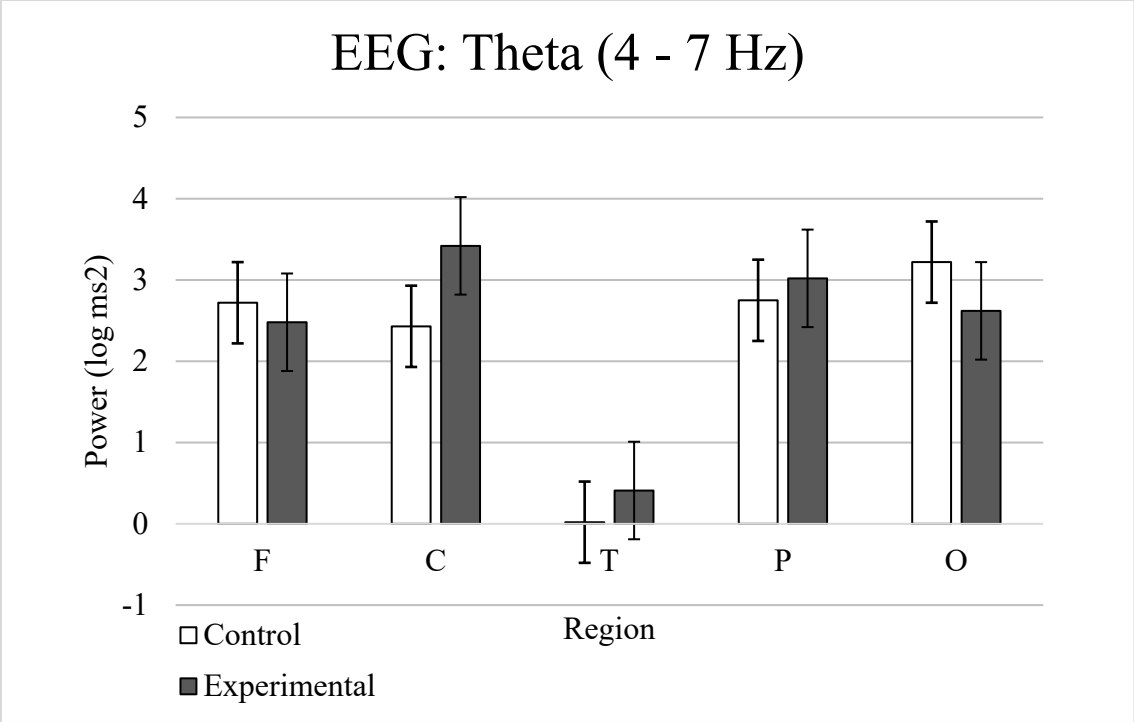


Figure 16. Graphical representation of the effect of theta power between conditions (experimental vs control) on brain regions; (**F**: frontal, **C**: central, **T**: temporal, **P**: parietal, **O**: occipital); error bar plotted with standard error; * $p < 0.05$

Table 5 *Correlation of EEG measures with HRV: SDNN*

	Pearson's R
Broad Band Alpha	-0.15
Low Alpha	-0.25
High Alpha	-0.17

Section 2: Challenge: Pre vs Post Training

Subsection 1: Breathing Rate

There were no differences in measures of breathing rate between conditions for pre-test and post-test (Table 8).

Table 6 *Comparison of HRV parameters between pre-test and post-test for both conditions.*

	Experimental				Control				
	Pre		Post		Pre		Post		
	M	SD	M	SD	M	SD	M	SD	*p*
Breathing Rate	21.1	2.7	19.3	4.2	21.4	3.8	19.8	3	NS

*$p < 0.05$

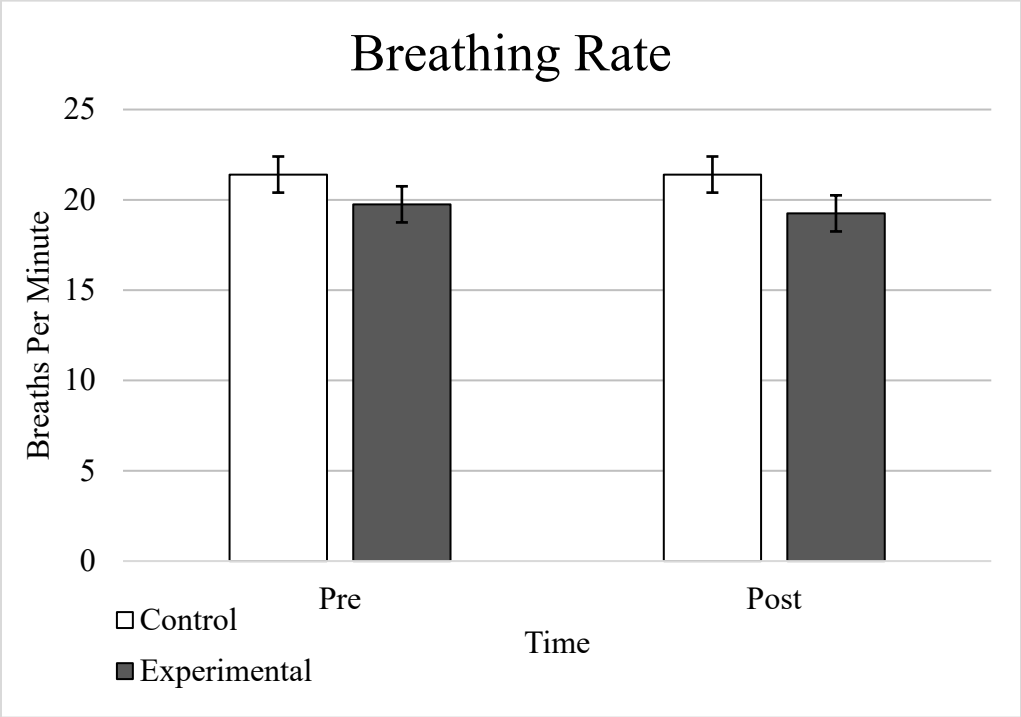


Figure 17. Comparison of breathing rate for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

Subsection 2: Heart Rate

There were no differences in measures of heart rate between conditions for pre-test and post-test (Table 6).

Table 7 *Comparison of HRV parameters between pre-test and post-test for both conditions.*

	Experimental				Control				
	Pre		Post		Pre		Post		
	M	SD	M	SD	M	SD	M	SD	*p*
Heart Rate	72	12	71.2	10.6	71.3	8.3	70.3	9.7	NS

*$p < 0.05$

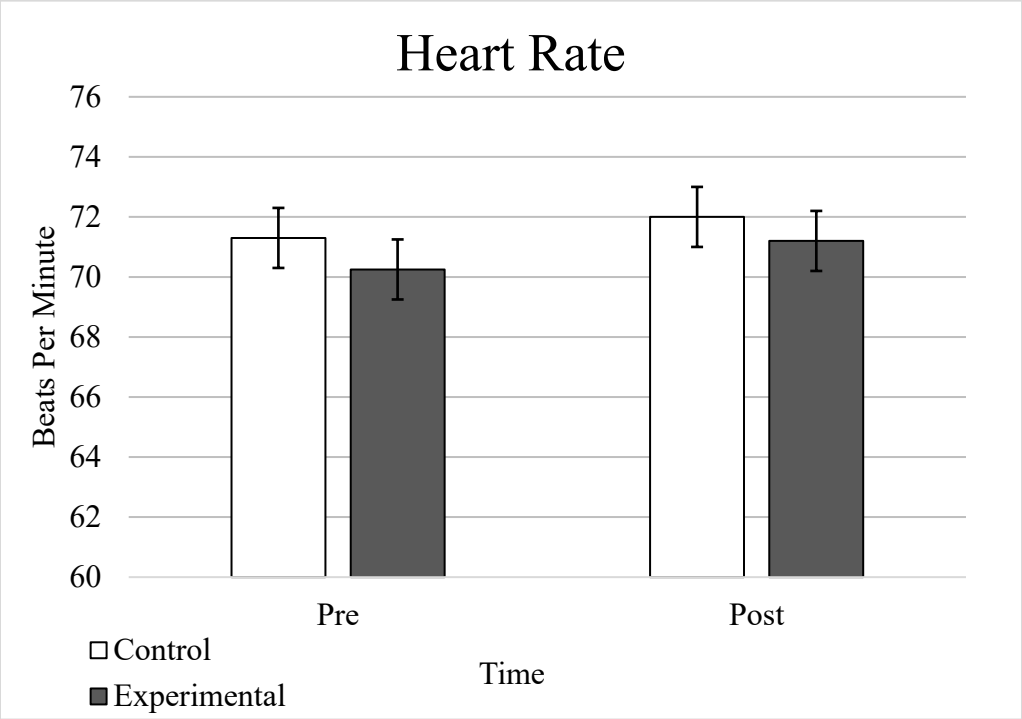


Figure 18. Comparison of heart rate for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

Subsection 3: HRV

There were no differences in measures of HRV including LF, HF, and TF power between conditions for pre-test and post-test (Table 7).

Table 8 *Comparison of HRV parameters between pre-test and post-test for both conditions.*

	Power (log ms^2)								
	Experimental				Control				
	Pre		Post		Pre		Post		
	M	SD	M	SD	M	SD	M	SD	p
SDNN	35.9	14.21	33.5	18.25	35.9	11.25	36.5	12.53	NS
HF	6.24	0.87	5.94	0.89	6.34	0.67	6.39	0.87	NS
LF	5.11	1.01	5.18	0.95	5.12	1.29	4.96	0.94	NS
TF	6.62	0.79	6.41	1.01	6.7	0.68	6.71	0.81	NS

* $p < 0.05$

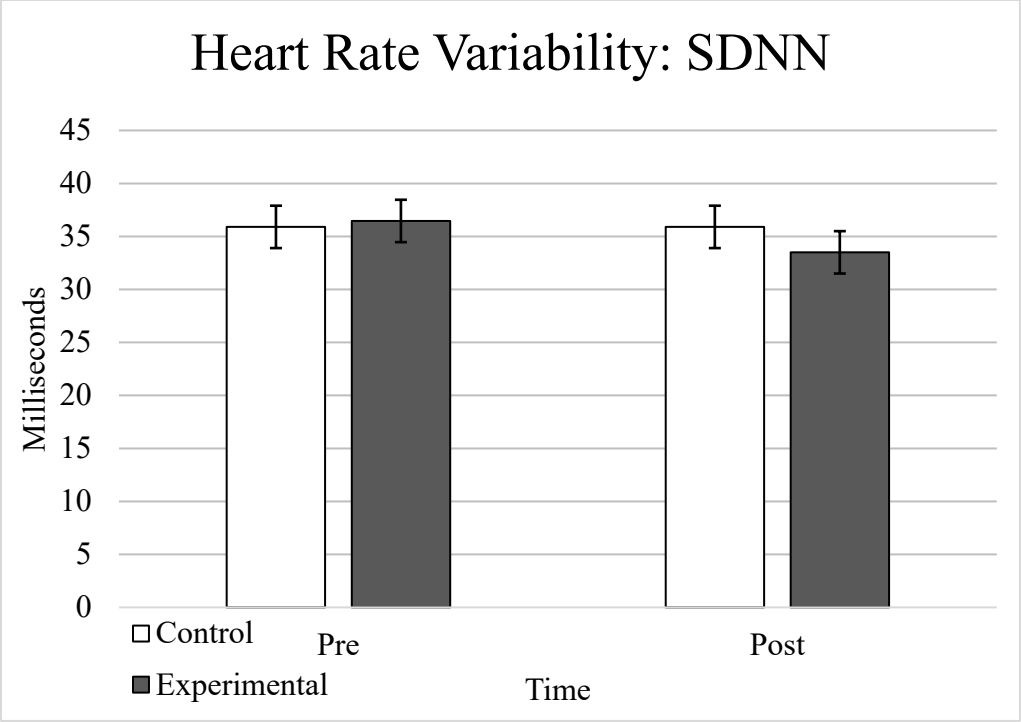


Figure 19. Comparison of SDNN HRV for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

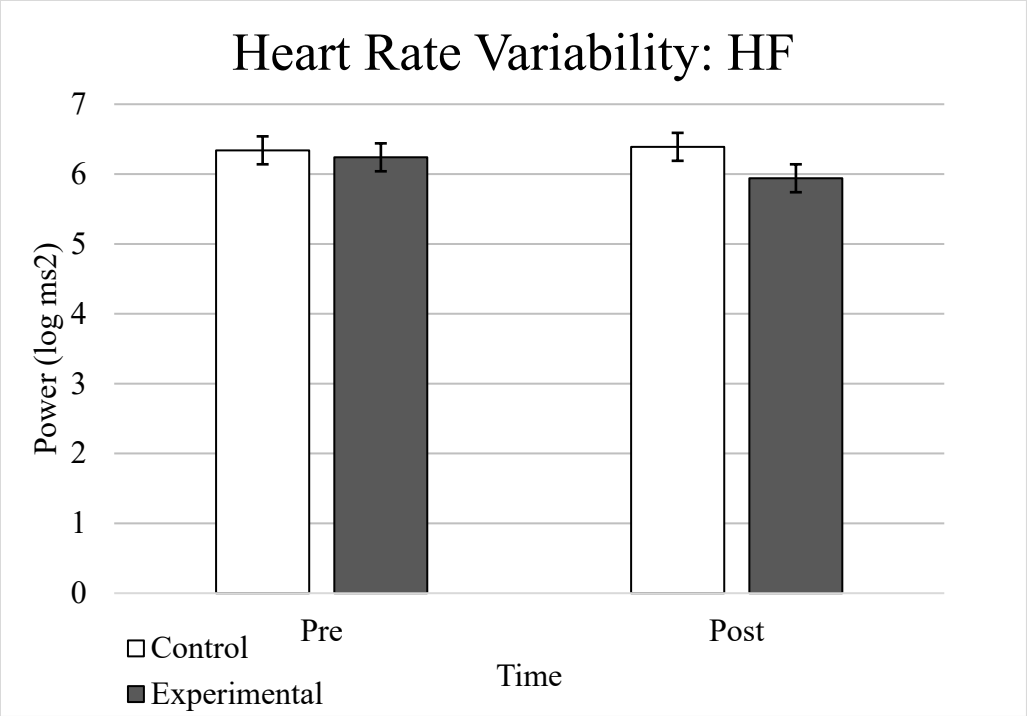


Figure 20. Comparison of HF HRV for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

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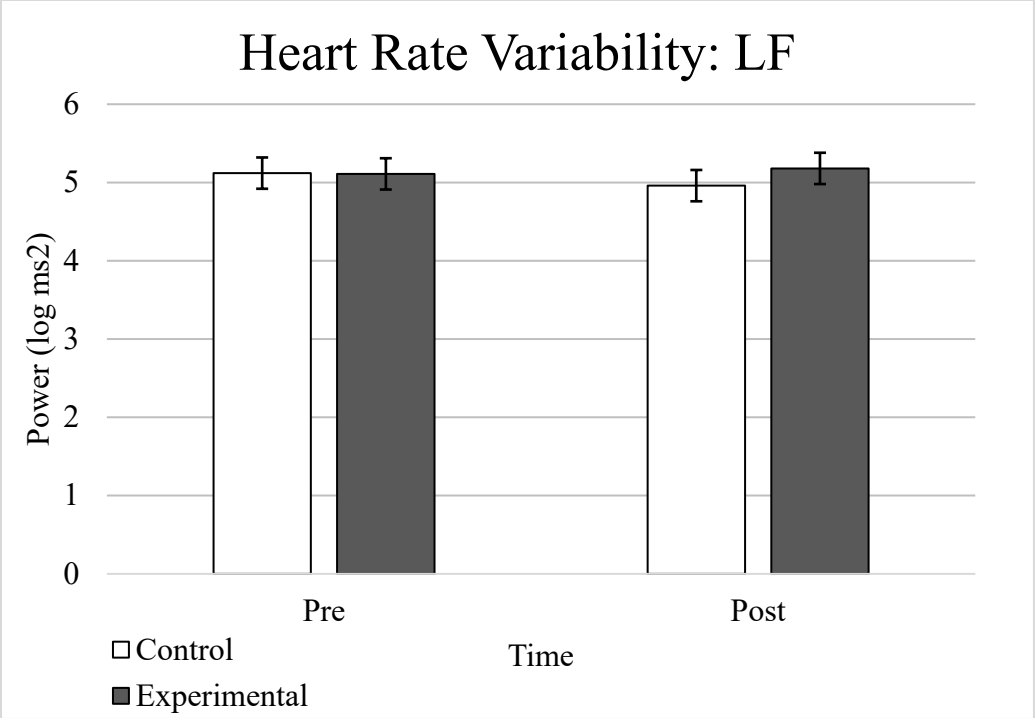


Figure 21. Comparison of LF HRV for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

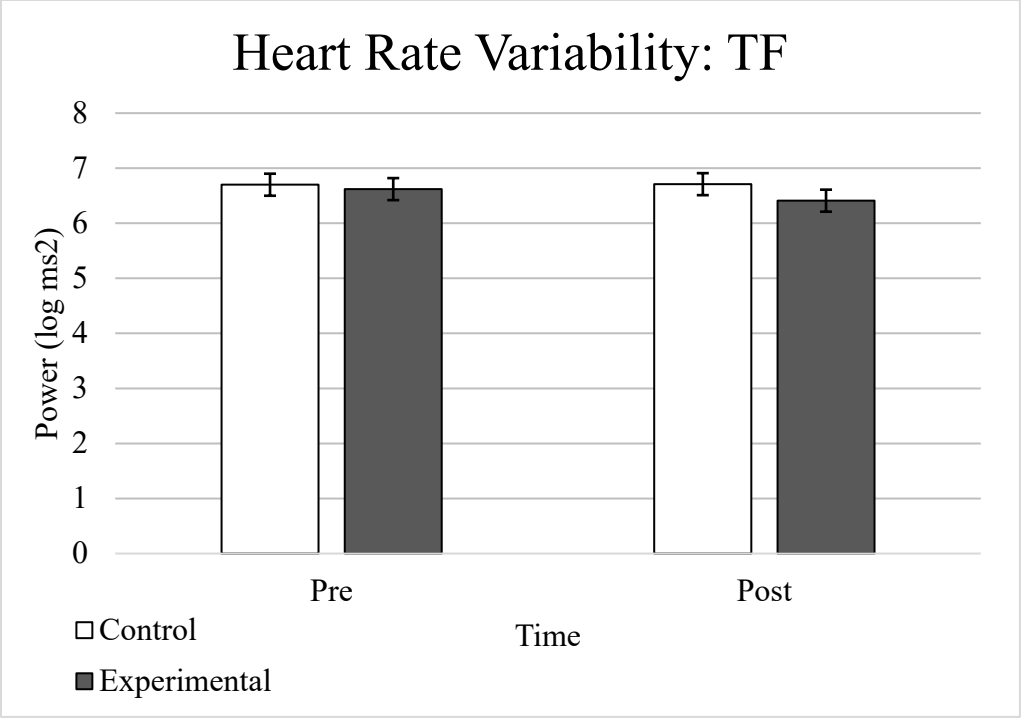


Figure 22. Comparison of TF HRV for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

Subsection 4: EEG

There were no differences in measures for alpha, low alpha, high alpha, and theta power between pre-test and post-test (Table 8).

Table 9 *Comparison of EEG parameters between pre-test and post-test for both conditions.*

	Mean EEG power (log μV^2)								
	Experimental				Control				
	Pre		Post		Pre		Post		
	M	SD	M	SD	M	SD	M	SD	p
Alpha	7.64	4.13	7.13	3.29	7.52	2.96	7.48	3.19	NS
Low Alpha	5.89	4.03	5.4	3.98	5.78	2.98	5.67	3.17	NS
High Alpha	1.14	4.66	.59	3.2	1.11	3.2	1.12	3.5	NS
Theta	3.62	3.86	2.92	2.31	3.53	3.13	3.18	2.97	NS

*$p < 0.05$

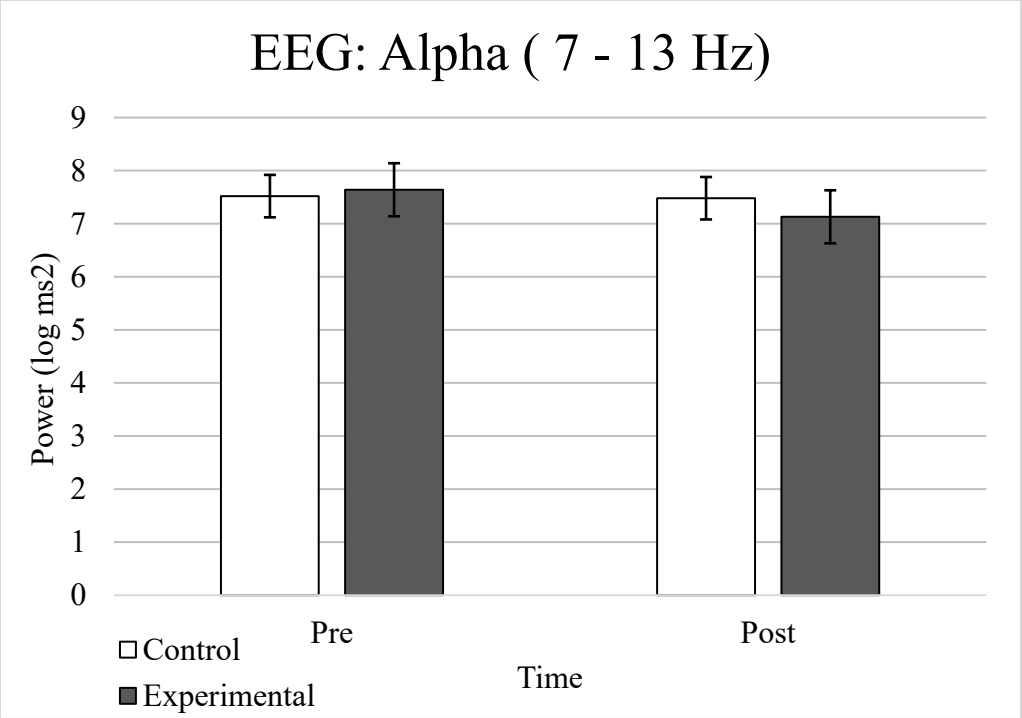


Figure 23. Graphical representation of alpha spectral power during pre-test and post-test. The EEG power from all five brain regions was averaged; error bar plotted with standard error; * $p < 0.05$

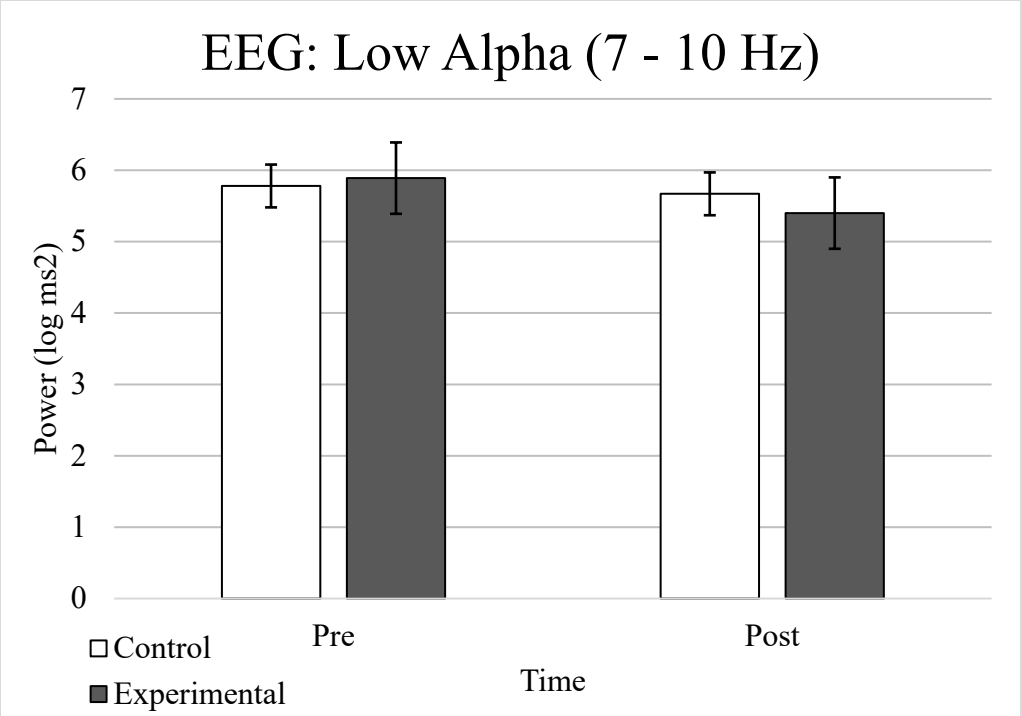


Figure 24. Graphical representation of low alpha spectral power during pre-test and post-test. The EEG power from all five brain regions was averaged; error bar plotted with standard error; * $p < 0.05$

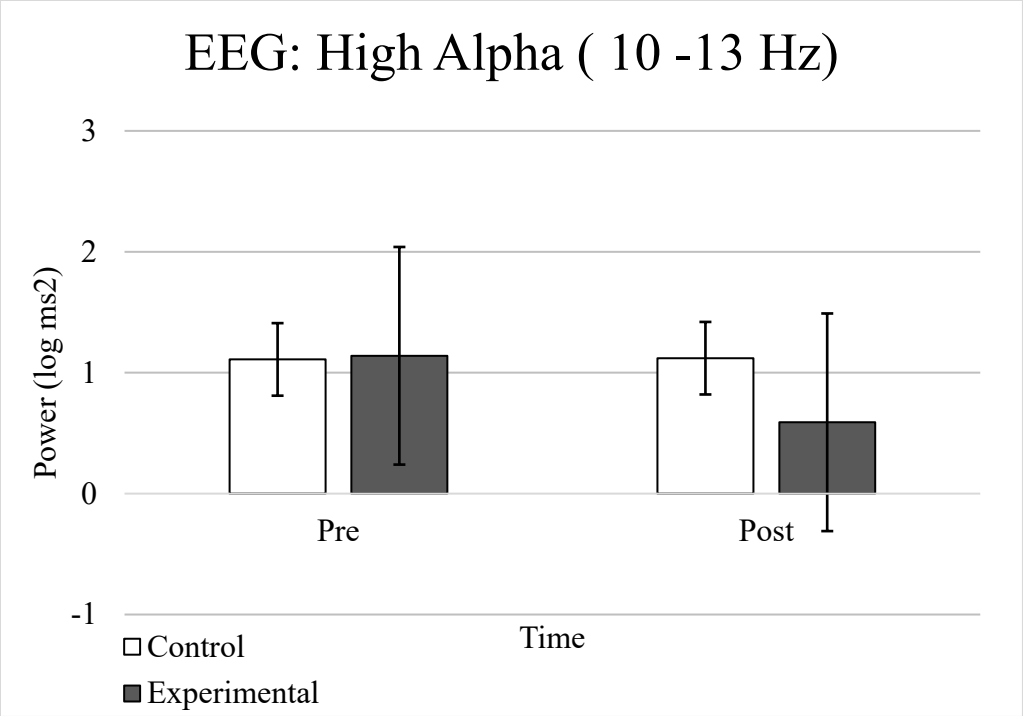


Figure 25. Graphical representation of high alpha spectral power during pre-test and post-test. The EEG power from all five brain regions was averaged; error bar plotted with standard error; * $p < 0.05$

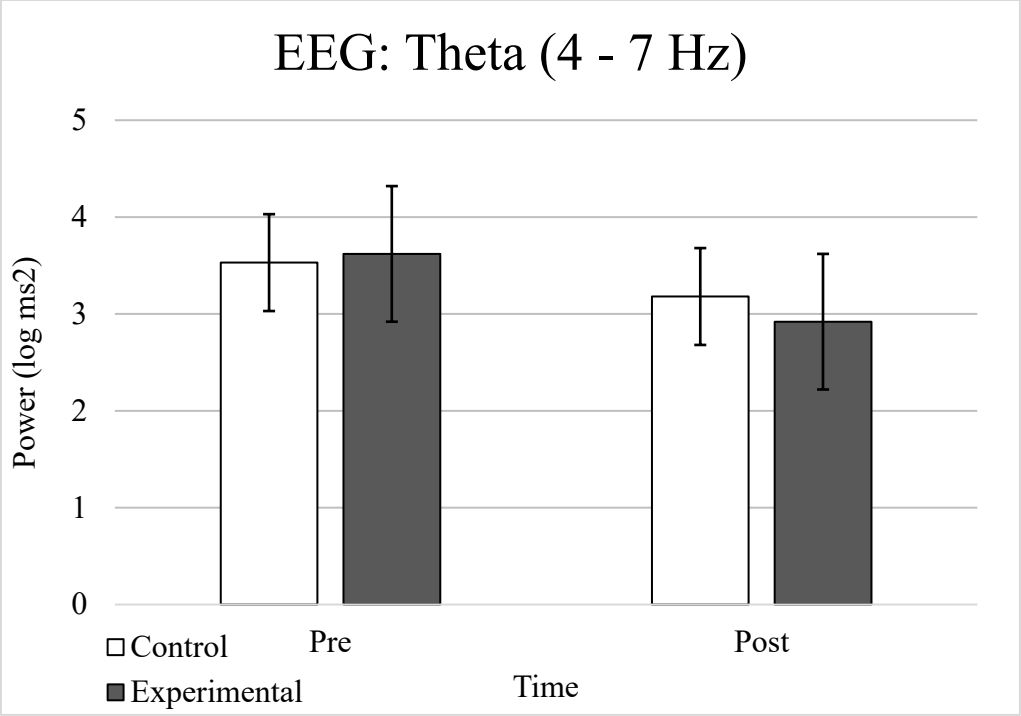


Figure 26. Graphical representation of theta spectral power during pre-test and post-test. The EEG power from all five brain regions was averaged; error bar plotted with standard error; * $p < 0.05$

Subsection 5: Subjective Response

There were no differences in measures of mental demand, temporal demand, performance, effort and frustration between pre-test and post-test (Table 9).

Table 10 *Comparison of NASA TLX parameters between pre-test and post-test for both conditions.*

	NASA TLX Score								
	Experimental				Control				
	Pre		Post		Pre		Post		
	M	SD	M	SD	M	SD	M	SD	p
Mental Demand	49.3	21	43.5	20.7	53.3	22.5	49.3	22.4	NS
Temporal Demand	64.8	21.4	53	23.9	66.5	21.6	55.3	20.4	NS
Performance	49	21.6	50.8	18.4	49.8	16.9	49.6	23.1	NS
Effort	58.5	20.7	47.8	24	60.8	23.1	56.5	19.2	NS
Frustration	43.3	24.4	37	23.3	43.8	21.5	41.8	21.2	NS

*$p < 0.05$

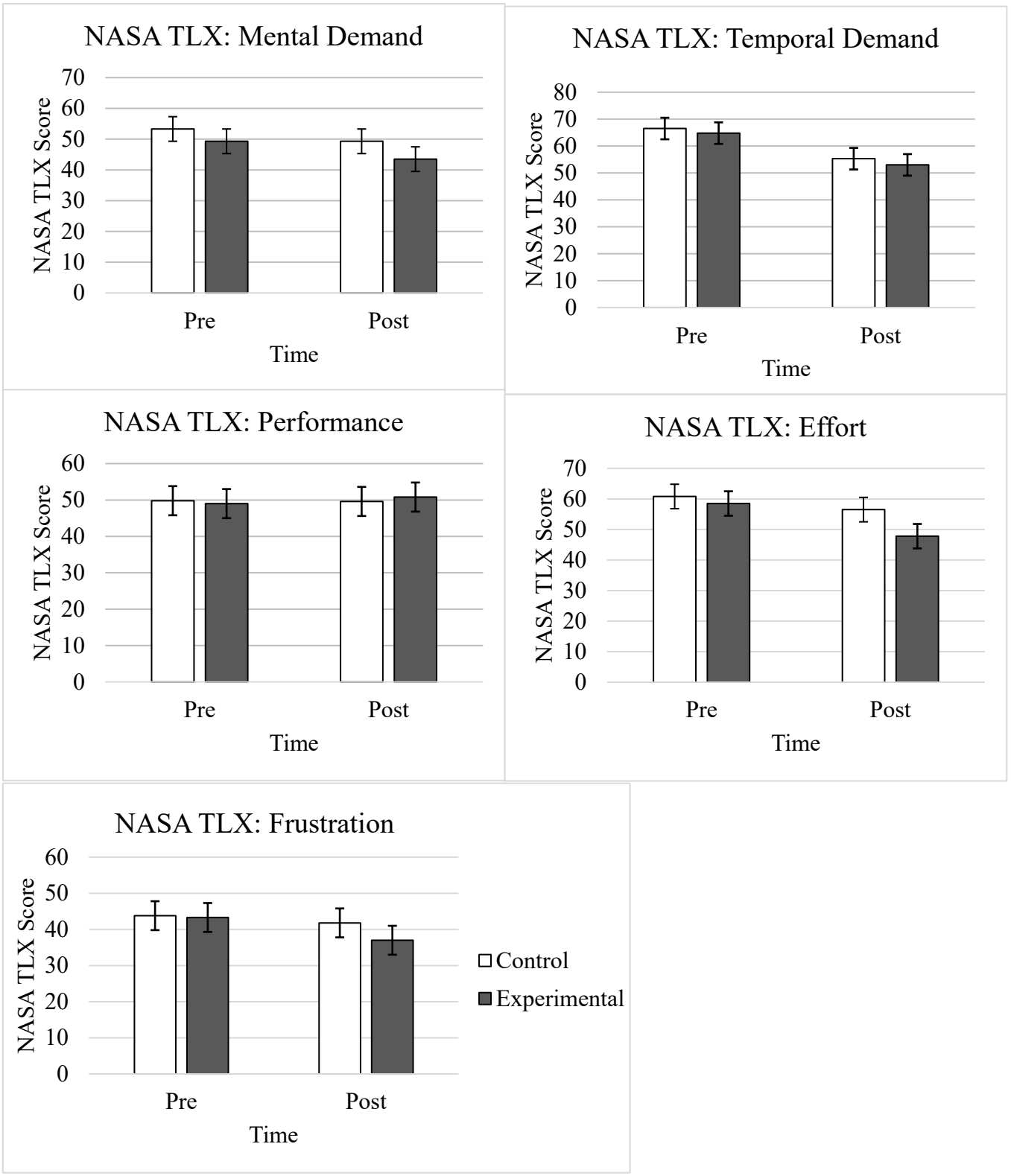


Figure 27. Comparison of NASA TLX for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

Subsection 6: Behavioral Performance

There were no differences in measures of performance including the number of game overs, the number of points scored, and the number of actions between conditions for pre-test and post-test (Table 10).

Table 11 *Comparison of HRV parameters between pre-test and post-test for both conditions.*

	Performance Score								
	Experimental				Control				
	Pre		Post		Pre		Post		
	M	SD	M	SD	M	SD	M	SD	p
# of game over	10.6	7.19	12.5	5.69	10.6	6.17	10.1	5.01	NS
# of points scored	81.9	25.9	85.3	23.8	87.3	20.6	87.6	23.1	NS
# of actions	515.9	79.3	516.6	76.5	525	70.9	527.2	88.7	NS

*$p < 0.05$

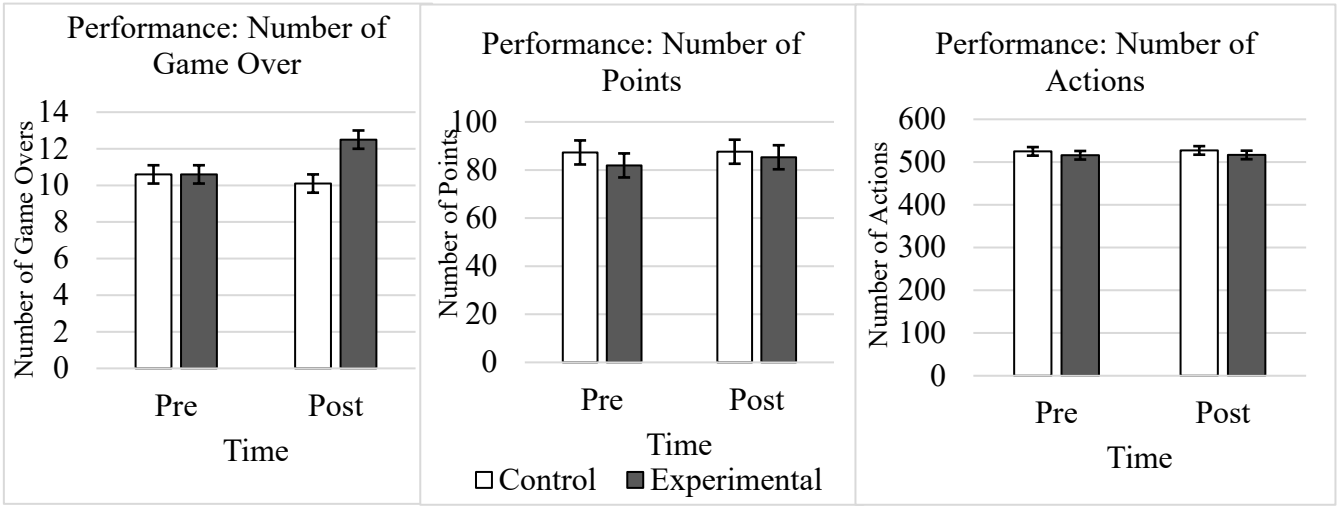


Figure 28. Comparison of game performance for experimental and control condition; error bar plotted with standard error; * $p < 0.05$

Chapter 13: Discussion

This chapter will be addressing the results presented in chapter 12. Firstly, the primary question will be examined, by revisiting the hypothesis based on the results, along with a discussion of the theoretical bases of the results. Second, the secondary question will be examined, by revisiting the hypothesis based on the results, along with a discussion on the theoretical bases of the results. Finally, discussions on the research limitation and future direction will also be included.

Section 1: Examine the Acute Effects of GVM

The findings of the study do provide psychophysiological evidence on the effects of acute GVM. There was an increase in parasympathetic activity reflected through the ECG and EEG measures. There was a statistically significant change in HR during the third trial between the experimental and control condition. This change in HR is a good reflection of the parasympathetic response as the participants undergone GVM, additional support for an increase in parasympathetic activity was through HRV measures. HRV results of the training period also shown an increase in SDNN, LF, and TF for the experimental condition compare to the control condition. While the results did not show a significant difference in HF between the experimental and control condition. The experimental condition exhibited a decrease in HR during the third trial of GVM. During the training period, alpha power was higher in the experimental condition compared to the control condition. Specifically, in the central and temporal regions of the brain.

Additionally, all three bands of alpha showed significant results compare to the control condition. While the results did not show a significant difference in theta power between the experimental and control condition. Additionally, a correlation was computed between SDNN and alpha power. However, results of the correlation did not yield an interaction between changes in alpha power and SDNN.

The findings of our study support previous findings of psychophysiological changes when undergoing GVM. Our results support the findings of Song and Lehrer (2003), there was an increase in LF and TF HRV power and a decrease in HF power. The HRV results support the current literature of changes in HRV when breathing at a fixed pace of 6 breaths per minute (Prinsloo et al., 2013; Vashcillo, 2002; Lehrer 2003; Song & Lehrer, 2003; Hassett, 2007, Rijken et al., 2016; Sherlin et al., 2010).

The results suggest GVM does promote a state of relaxation through an increase in alpha power, which is in line with the results of other literature that utilized GVM to assess cortical changes (Sherlin et al., 2010; Dziembowska et al., 2015; Prinsloo et al., 2013). Although the results of our experiment did now show any changes in theta power, compare to the previous literature that examined cortical dynamics undergoing GVM (Sherlin et al., 2010; Dziembowska et al., 2015; Prinsloo et al., 2013), due to the participants were novices who had never undergone GVM training. Therefore, their attentional focus on self-regulation is not well-trained compare to previous studies where individuals had undergone weeks of GVM training.

Previous literature has revealed that GVM has restorative effects on autonomic function (Lehrer, 2007). The findings of this study are in keeping with

other studies which show similar effects on cortical dynamics and cardiovascular changes in response to GVM (Sherline,2010). Increased alpha power reflects a state of relaxation (Cahn & Polich, 2006), studies have also shown GVM to decrease anxiety and depression (Goessl, Curtiss, & Hoffman, 2017). Results from this study show GVM can elicit an immediate effect on cortical and cardiovascular activity. Leading to a shift in PNS activity or increase relaxation, as suggested by the data from EEG and HRV.

Section 2: Performance Enhancement Effects of GVM

The finding of our study did not find any statistical improvement compared to the experimental and control condition post-intervention. Through GVM it did not result in an improvement in stress resilience or enhancement on performance compared to the control condition. No statistically significant changes in cortical dynamics, HRV, subjective response, and performance, post-intervention between the experimental and control condition.

The findings of our study did not find any improvement in performance on the snake task. We did not observe any cortical refinement during the challenge for the participant's post- GVM. Unlike Prinsloo et al. (2013) and Sherlin et al. (2010), we did not find a performance enhancement of acute GVM. However, the nature of the task is different from our experiment that utilized a cognitive-motor task compared to the executive function test. Both experiments utilized a Stroop test and found a decrease in errors compared to the control condition. While for our study we did not have any statistically significant changes in performance between the two conditions. As stated previously participants were novices and were experiencing slow-paced

deep breathing training for the first time. Therefore, it would seem highly unlikely for performance enhancement to occur for a more complex cognitive motor task. Although, perhaps after extended sessions of training GVM may lead to a performance in the complex psychomotor task.

Section 3: Research Limitations and Future Directions

A significant limitation of this study is that we were assessing the acute effects of a single GVM session. It is possible that long-term EEG changes during task engagement may occur when practiced over multiple sessions. Future research efforts will focus on providing more training sessions to observe changes in cortical dynamics of resting states and challenge.

There was a small degree of differences in our results compare to the literature of previous studies that had utilized GVM and employing EEG. Although there are similarities in the results, our participants did not respond the same way as other participants in studies that examined single session GVM. As such, any cortical refinement may require more training sessions for a change in cortical dynamics and performance enhancement to occur.

Through this experiment, we have observed that GVM can have a quick effect on healthy individuals who are not under high mental stress. The recruited participants of the study are all healthy physically and mentally, in comparison to individuals who suffer from any mental disorders such as depression, anxiety, or traumatic stress disorder. Therefore, the impact of GVM would be easier to quantify on participants with higher levels of stress rather than participants who are relatively relaxed and stress-free.

Chapter 14: Conclusion

Overall, this study aimed to investigate the acute effects of GVM. With no prior training or experience in deep slow-paced breathing, there is a substantial effect of this relaxation technique on CNS and ANS activity. With many previous studies providing supporting evidence on changes in cardiovascular and ANS activity. This study provides better insight into the neurological changes (i.e., CNS) when individuals perform a GVM. Specifically, an increase in alpha power, leading to cortical relaxation.

Therefore, it is plausible that with more practice session changes in CNS and ANS activity will be more dramatic compared to the control group. With this GVM training, it is possible to elicit greater PNS activity allowing individuals to improve emotional and stress regulation. Additionally, with more training sessions it may be possible to increase performance in more complex cognitive-motor tasks.

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