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DIAPHRAGMATIC BREATHING AND ITS EFFECT ON INHIBITORY CONTROL

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
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By

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Lexington, Kentucky

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ABSTRACT OF THESIS

DIAPHRAGMATIC BREATHING AND ITS EFFECT ON INHIBITORY CONTROL

Evidence suggests that slow paced diaphragmatic breathing (DB) can significantly affect prefrontal cortex functions through increasing an individual's physiological self-regulatory capacity. The current research demonstrates the effects of paced DB on inhibitory control, which is considered to be a reliable measure of behavioral self-regulation. Eighty healthy participants were randomly assigned to one of two conditions (20 males and females each). Participants were instructed on either DB at a pace of six-breaths per minute (BPM) or instructions on environmental awareness and asked to breathe at 12 BPM. Following training, all participants completed a computer-based task designed to examine inhibitory processes. Physiological recordings of heart rate (HR), BPM, and HRV were collected at baseline, during the breathing training, during the cued go/no-go task, and after the cued go/no-go task. The findings demonstrated that the DB condition had significantly lower BPM, HR, and higher HRV (p's<0.05) during active training than the environmental awareness condition. Furthermore, the DB condition performed significantly better on the measure of inhibition than the environmental awareness condition ($p<0.05$). The use of DB as a reliable method to increase physiological self-regulatory capacity and improve behavioral self-regulation, measured as inhibitory control, should continue to be explored.

KEYWORDS: Diaphragmatic Breathing, Entrainment, Inhibition, Cued Go/no-go Task, Automated Training

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Chapter One: Introduction

Self-regulation is defined as the ability to respond appropriately to external stimuli by using available psychological and physiological resources. Self-regulation has been linked to emotion regulation, control of sleep onset and duration, respiratory functions, and inhibitory control (Brown, Gerbarg, & Muench, 2013; Litchfield, 2003; Porges, 2007; Thayer & Lane 2009). Furthermore, self-regulatory capacity has been implicated in the management of motion sickness, Parkinson's disease, and chronic pain conditions (Russell, Hoffman, Stromberg, & Carlson, 2014; Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Burris, Evans, & Carlson, 2010). Previous literature has suggested that self-regulation can be altered by voluntarily controlling breathing patterns (Fried & Grimaldi, 1993; Lehrer, Vaschillo, & Vaschillo, 2000; Russell, Scott, & Carlson, unpublished results; Thayer et al., 2009). The exercise of voluntary breathing control has generated a significant number of studies recently (Courtney, Cohen, & van Dixhoorn, 2011; Ferreira et al., 2013; Henriques et al., 2011; Lehrer et al., 2000; Lin et al., 2012; Patron et al., 2013; Sauer, Burris, & Carlson, 2010; Whited, Larkin, & Whited, 2014). Given that self-regulation capacity is linked to a variety of cognitive, emotional, and physical outcomes, the present study sought to explore how volitionally altering breathing pace and mechanics could improve cognitive functioning.

One area that has received concentrated interest from self-regulation research is behavioral inhibition or behavioral self-regulation (Heatherton & Wagner, 2010; Thayer & Lane, 2000). The inhibition of behaviors can be defined as the exertion of cognitive and physiological self-regulation systems to stop a behavior no longer adaptive for the present environment (Brass & Haggard, 2007; Thayer et al., 2009). For instance,

behavioral inhibition is observed when a driver trained to drive on the right side of the road in the U. S. must inhibit that impulse when in England and drive on the left side of the road in that country. Although adaptive to drive on the right side of the road in the U.S., self-regulation must be exerted by U.S. trained drivers to refrain from driving on the right side while in England. When a U.S. trained driver reverts to driving on the right side of the road in England, one can argue that there has been a failure of inhibitory control. Failures within the inhibitory system, while not always as obvious as the driving example, have been linked to a wide variety of disorders including anxiety, depression, attention-deficit hyperactivity disorder, and alcoholism (Litchfield, 2003; Thayer et al., 2009). Difficulties in self-regulation also are mirrored in ongoing physiological processes (Fried & Grimaldi, 1993).

Physiology of Self-regulation

Effective behavioral self-regulation requires the adaptive balance of various physiological systems in the body. For instance, when attempting to inhibit a thought or behavior, neural circuits involved in both cognitive and physiological regulation must identify and process relevant information while ignoring non-essential information (Thayer & Lane, 2000). Once the brain identifies the most pertinent information for an environmentally adaptive response, it must decide whether to interrupt an ongoing behavior and re-allocate resources for the initiation of other behaviors (Thayer & Lane, 2000). According to Thayer & Lane's (2009) neurovisceral integration model, this process is done automatically and can be viewed as physiological self-regulation framework that precipitates and allows for behavioral self-regulation. Their model originated with Claude Bernard who insisted,

> "…that when the heart is affected it reacts on the brain; and the state of the brain again reacts through the pneumo-gastric (vagus) nerve on the heart; so that under any excitement there will be much mutual action and reaction between these, the two most important organs of the body" (Darwin, 1999, pp. 71-71).

Bernard outlined the bidirectional communication system between the brain and heart involving the prefrontal cortex, amygdala, medulla, hypothalamus, and various other neural structures (Thayer & Lane, 2009). The intimate brain and heart connection allows for rapid changes in cardiac functioning in response to ever changing environmental demands (Porges, 2007; Thayer & Lane, 2009). In the paragraphs that follow, the more salient biological systems involved in self-regulation, including autonomic nervous system domains, cardiovascular functioning, and respiratory parameters will be reviewed.

Autonomic Nervous System

The two major branches of the autonomic nervous system originate from the brain stem and contribute to the regulation of functions within the eyes, sweat glands, blood vessels, heart, larynx, trachea, bronchi, lungs, stomach, and other target systems (Porges, 2007). In response to external stimuli, the sympathetic nervous system (SNS), commonly known as the *fight or flight* response, promotes an amplified state of arousal through increased metabolic activity, cardiac activity, and respiration rate. The parasympathetic nervous system (PNS) manages the conservation of energy through decreased metabolic activity, reduced cardiac output, and slowed respiration. The PNS operates as an SNS antagonist and is commonly referred to as the *rest and digest* response (Dodd & Role,

1991). The PNS's role in self-regulation was first outlined with Porges's *Polyvagal Theory*.

Although the autonomic nervous system's two branches were thought to operate like a seesaw, Porges proposed that autonomic arousal is in fact modulated by the PNS. The *Polyvagal Theory* argues that the body's state of arousal is governed through the PNS's tonic inhibitory control via cranial nerve X (vagus). The vagus nerve, which contains 75% of the PNS's fibers, functions as a braking system ("vagal brake") allowing sympathetic arousal when withdrawn and inhibition of sympathetic arousal when applied. The vagus nerve accomplishes this task via its innervation (to supply nerves that allow for control) of the heart (Hall & Guyton, 2011; Porges, 2011). Specifically, the PNS's strong influence over the vagal nerve, allows it to function as a "super highway" to the heart's pacemakers (sinoatrial and atrioventricular nodes) and thereby rapidly affect heart rate (Porges, 2011).

According to the *Polyvagal Theory*, application of the *vagal brake* reduces sympathetic arousal, respiration rate, and heart rate; this allows for calmer engagement with environmental challenges. Withdrawal of the *vagal brake* results in the opposite physiological reaction, i.e. promotion of SNS tone, and facilitates escape from unsafe environmental stimuli. The inhibition of SNS tone, via the vagal nerve has been recorded and studied as heart rate variability (HRV) (Berntson et al., 1997; Grossman, 1992; Porges, 2007 & 2011).

Breathing and Heart Rate Variability

The vagus nerve's ability to affect cardiac function led researchers to examine cardiovascular parameters that might be linked to both physiological and behavioral self-

regulatory capacity (Porges, 2007). One of the more reliable ways to measure vagal nerve influence on the heart is through HRV (Grossman, 1992; Porges, 2007). HRV refers to the variability of the time interval between heartbeats and serves as a reliable marker of vagal influence (Berntson et al., 1997). A traditional measure of HRV is referred to as respiratory sinus arrhythmia (RSA) because it accounts for the natural variation of the heartbeat during the inspiration (increasing heart rate) and expiration (slowing heart rate) phases of the respiratory cycle (Berntson et al., 1997). The measurement of RSA is considered a reliable way to examine vagal influence over the heart and its discovery has encouraged the use of respiration modifications for the purpose of deliberately altering HRV.

Intentional manipulation of cardiac function through changes in breathing pattern and rate is an established approach to improving self-regulatory capacity (Carlson et al., 2001; Denver, Reed, & Porges, 2007; Elliot, Payen, Brisswalter, Cury, & Thayer, 2011; Lehrer et al., 2000; Lehrer et al., 2010; Vaschillo et al., 2008). Low resting HRV has been proposed as a marker for anxiety disorders, panic disorders, and gastrointestinal disorders; on the other hand high HRV has been proposed as a protective factor for chronic pain disorders, breathing disorders, motion sickness, and both physiological and behavioral self-regulatory fatigue (Carlson et al., 2001; Fried & Grimaldi, 1993; Gyurak & Ayduk, 2008; Lehrer et al., 2006; Litchfield, 2003; Russell et al., 2014; Solberg Nes, Carlson, Crofford, de Leeuw, & Segerstrom, 2011; Thayer & Lane, 2007; Thayer, Ahs, Fredrikson, Sollers, & Wagner, 2012; Vaschillo et al., 2008). A reliable method for increasing HRV tone has been to slow an individual's breathing rate (Jerath, Edry, Barnes, & Jerath, 2006; Joseph et al., 2005). According to Lehrer et al. (2010),

maximizing the effects of breathing rate for increasing HRV requires a pace of 3-7 breaths-per-minute along with diaphragmatic breathing mechanics. Since HRV has been linked to self-regulatory capacity, the deliberate control of HRV by manipulation of respiratory parameters through controlled diaphragmatic breathing appears to be a means for directly influencing both physiological and behavioral self-regulation capacity.

Diaphragmatic Breathing

Although the principal functions of the respiratory system are infusing oxygen and managing carbon dioxide levels in the body's tissues, the control of respiration has been linked to physiological self-regulation capacity (Fried & Grimaldi, 1993; Hlastala & Berger, 2001). Normal respiration primarily uses two major muscle groups including the diaphragm, an internal skeletal muscle located beneath the lungs, and the intercostal muscles, which are located between the ribs. The diaphragm acts as the primary breathing muscle, and the intercostal muscles assist the diaphragm by increasing the spacing of the ribs and contributing to an increase in the volume of the chest cavity when they contract. The diaphragm, which is connected to the bottom of the rib cage, functions by contracting from its domed-like shape to a flatter position. As the diaphragm flattens and creates a larger chest cavity, the increase in chest cavity volume results in a partial vacuum that draws air into the lung tissues (Wilhelm, Gevirtz, & Roth, 2001). The flattening of the diaphragm puts pressure on the internal organs below it (liver, stomach, intestines) so there is observable outward movement of the abdomen during normal inspiration.

When there is an increase in sympathetic drive, there is a corresponding increase in the use of the intercostal muscles and the secondary muscles of inspiration (e.g.,

scalenes, sternocleidomastoid, upper trapezius, and cervical paraspinal muscles) to increase the chest cavity space by chest movement upwards and outwards. The use of these muscle systems results in a significant volume of air drawn into the lungs on inspiration and consequently leads to a significant volume of air released from the lungs on exhalation. The use of the secondary muscles of inspiration is important because it allows the individual under stress to obtain greater lung volume and thus increases access to oxygen and facilitates greater release of carbon dioxide to the atmosphere. During less stressful periods, however, if diaphragmatic breathing mechanics are used, there is efficient transfer of oxygen rich air into the blood on inspiration and appropriate release of carbon dioxide to the atmosphere on exhalation (Fried & Grimaldi, 1993).

Cognitive Implications of Self-regulation

Previous research has shown that individuals with enhanced physiological self-regulation demonstrated improved cognitive performance on memory tasks, emotional reactivity tasks, and inhibitory control tasks (Denver et al., 2007; Elliot et al., 2011; Lehrer et al., 2010; Lehrer et al., 2013; Mun, Von Eye, Bates & Vaschillo, 2008; Porges, 2007; Vaschillo et al., 2008). Deficits in physiological self-regulation have also been tied to an individual's inability to cope with environmental demands or regulate inappropriate behaviors (Thayer & Lane, 2009). Although rapid reduction of tonic inhibitory PNS control over sympathetic arousal is adaptive for environmental danger, hypersensitivity of the system to environmentally safe stimuli or failure to recognize safety signals has been linked to hypoactivity of critical areas of the prefrontal cortex. According to Thayer & Lane (2009) hypoactivity of the prefrontal cortex is associated with disinhibition of sympathoexcitatory circuits responsible for energy appropriation. Prolonged up-

regulation of this system has been linked to several psychopathological disorders characterized by a lack of inhibitory control over neural processes and thus a reduction in executive functioning similar to those found in generalized anxiety disorder, panic disorder, post traumatic stress disorder, and schizophrenia (Thayer & Lane, 2009). Therefore, reversing this maladaptive or inappropriate autonomic up-regulation through increased vagal stimulation via slow diaphragmatic breathing may result in improved executive functioning, and particularly an improvement in inhibitory control processes.

Psychophysiology of Self-regulation

Several researchers posit that the autonomic nervous system, through bidirectional pathways, self-regulates the executive and affective processes of working memory, attention, response inhibition, emotion reactivity, affective set-shifting, and extinction (Porges, 1992; Porges, 2007; Thayer & Lane, 2009). Influence over these systems is maintained through the central autonomic network (CAN) that includes, but is not limited to, the nucleus tractus solitarii, nucleus ambiguus, dorsal vagal motor nucleus, central nucleus of the amygdala, and hypothalamus (Thayer et al., 2009). Thayer has suggested the CAN is directly linked to HRV control through its influence of the sinoatrial node, the heart's primary pacemaker (Thayer et al., 2011). The CAN is reciprocally influenced by cardiac function through the control of blood pressure via the baroreflex (Thayer & Sternberg, 2009). The baroreflex serves as the primary bidirectional system by which the brain and heart maintain homeostasis of blood flow and blood pressure (Hall & Guyton, 2011). The vagus nerve, therefore, is part of a "major highway" that links various cognitive functions with the heart and influences HRV. Consequently it is reasonable to

consider HRV as a window into the inner workings of this complex bidirectional system that allows the brain and the heart to communicate.

Psychophysiology of Inhibition

The psychological construct of inhibition can be defined as the suppression of inappropriate responses when context or environment is changed (Aron, Robbins, & Poldrack, 2014). It has been argued that the overlap between systems implicated in self-regulation and inhibitory control allows for alteration of cardiac function, via HRV, to suppress or inhibit inappropriate behavioral responses to external stimuli (Elliot et al., 2011; Thayer et al., 2009). Additional research has demonstrated that stimulation of the CAN and its innervation of the prefrontal cortex including structures like the ventrolateral prefrontal cortex, typically associated with inhibitory control, facilitates improved performance on traditional tests of inhibition and can be viewed as behavioral self-regulation (Buckman, White, & Bates, 2010; Lehrer et al., 2013; Saus, Johnsen, Riisem, Andersen, & Thayer, 2006; Vaschillo et al., 2008). Given the importance of the CAN for regulating inhibition it is important to consider what factors influence the extent to which the CAN governs inhibitory control.

Moderators of Self-regulation and Inhibition

There are several potential variables known to effect performance on inhibitory control tasks. These variables include impulsivity, sensation seeking, and proclivity for problem drinking behaviors. In previous literature investigating inhibitory control, impulsivity, sensation seeking, and alcohol use have been indicated as potential sources of variance (Fillmore & Rush; 2001; Fillmore, Ostling, Martin, & Kelly, 2009; Hitter & Swickert, 2006; Marczinski & Fillmore, 2003; Zuckerman, Kuhlman, Joireman, Teta, &

Kraft, 1993). Therefore, although their effects on inhibitory control should be reduced through random assignment of participants, it was important to investigate their potential moderating effects.

Impulsivity and Sensation Seeking

Costa and McCrae defined the personality trait of impulsivity as the tendency to act on cravings and urges rather than controlling them and delaying gratification (Costa & McCrae, 1996). Previous literature found that individuals who scored higher on measures of trait impulsivity or suffered from self-control disorders performed poorly on inhibitory control tasks relative to control participants (Fillmore & Rush, 2001). In addition, Thayer et al. (2009) suggested high impulsivity individuals would not only perform more poorly on tasks measuring inhibition than control condition participants but they are also more likely to have lower resting levels of physiological self-regulatory capacity than control participants. For these reasons, it is important to insure that the trait of high impulsivity is not unduly influencing experimental outcomes.

In addition, the personality trait of sensation seeking may play a role in inhibitory control (Fillmore et al., 2009). Zuckerman (1994) defined sensation seeking as pursuing varied, novel, complex, and intense sensations or experiences, with the willingness to take physical, social, legal, and financials risks. Moreover, in Zuckerman's personality model, sensation seeking is associated with impulsivity (Zuckerman et al., 1993). Due to the connection between sensation seeking, impulsivity, and inhibitory control the Zuckerman Sensation Seeking Scale Form V (SSS-V) was included to examine sensation seeking's potential moderating role between self-regulation training via the breathing intervention

and improved inhibitory control on participants' cued go/no-go task performance (Zuckerman et al., 1993; Zuckerman et al., 1978).

Drinking Behaviors

Participants' drinking behavior is also a potential moderator of inhibitory control. In previous literature, drinking behaviors were associated with high levels of impulsivity and sensation seeking (Beirness, 1993; Donovan, Marlatt, & Slazberg, 1983; Ernst et al., 2006; Fillmore, Blackburn, & Harrison, 2008; Cyders et al., 2007; White, Labouvie, & Papadaratsakis, 2005). Drinking behavior is often measured by, the Personal Drinking Habits Questionnaire (PDHQ) and the Alcohol Use Disorder Identification Test (AUDIT) (Vogel-Sprott, 1992; Saunders, Aasland, Babor, Fuente, & Grant, 1993). Therefore, it is reasonable to use such measures in the study of inhibitory control in order to carefully evaluate their possible influence on behavioral outcomes.

The Present Study

The intent of the present study was to evaluate the efficacy of a recently developed protocol to strengthen physiological self-regulatory capacity through instruction on respiration mechanics, respiration rate, and the structure of the breathing cycle. The research question focused on whether an automated breathing protocol could alter measures of behavioral self-regulation in regards to improved performance on a task of inhibitory control. Automation of breathing training is important because it allows research findings associated with breathing entrainment protocols to be quickly and accurately replicated. The ability of the present intervention to increase behavioral self-regulation was tested with a cued go/no-go task, which has served as a reliable indicator of inhibitory control in previous research (Fillmore et al., 2008; Fillmore et al., 2009). In

order to quantitatively measure the effects of the breathing intervention on the cued go/no-go task, traditional markers of physiological self-regulatory capacity including breathing rate, heart rate, and HRV were recorded (Eddie et al., 2013; Buckman et al., 2010; Elliot et al., 2011; Lehrer et al., 2010; Lehrer et al., 2013; Mun et al., 2008; Song & Lehrer, 2003; Thayer et al., 2009). Participants' response accuracy during the cued go/no-go task will be recorded as a measure of participants' behavioral self-regulation or participants' ability to successfully inhibit incorrect responses.

Breathing Rate and Rest Period

Previous work has demonstrated the importance of breathing rate and mechanics for successful manipulation of both physiological and behavioral self-regulatory capacity (Lehrer, Smetankin, & Potapova, 2000; Lehrer et al., 2000; Vaschillo, Lehrer, Rishe, & Konstantinov, 2002; Lehrer et al. 2000; Russell et al., 2014; Russell et al., unpublished results; Vaschillo, Vaschillo, & Lehrer, 2006). Diaphragmatic breathing at a rate of 3-7 breaths per minute is the most natural and effective way to effect self-regulation (Carlson et al., 2001; Fried & Grimaldi, 1993; Lehrer et al., 2000; Russell et al., unpublished results). Although no known published research to date has demonstrated the potential benefits of altering the structure of the respiration cycle through the inclusion of a rest period, the validity of a three stage breathing cycle has been demonstrated on three separate occasions (Russell et al., unpublished results; Russell et al., 2014; Kniffin et al., 2014). The use of a rest period in between the inhalation and exhalation cycles of respiration may function as a way to magnify the effects of the breathing manipulation on the physiological biomarkers for increased self-regulation. Therefore, the present study

examined a three-stage breathing protocol's effect (4 second inhale; 2 second exhale; 4 second rest period, 424) on the cued go/no-go task.

Hypotheses

With the ability to quantify behavioral self-regulation (e.g., operationalized as inhibitory control) with participants' accuracy on the No-go trials of the cued go/no-go task, the intent was to measure the effects of the automated breathing protocol on participants' physiological biomarkers of self-regulation (breathing rate, heart rate, and HRV) and draw causal conclusions of their effects on inhibitory control. It was predicted that the control condition's physiological measures would not be significantly changed from baseline, while the experimental condition, who followed the three-staged breathing protocol, would show slowed respiration rates and improved HRV tone (indications of increased physiological self-regulation). It was also predicted that participants would perform better on specifically the No-go portion of the cued go/no-go task, which served as a test of inhibition and behavioral self-regulation, if they followed the three-stages breathing protocol as compared to those in the control condition. Finally, the study explored the potential role of impulsivity, sensation seeking, and drinking behaviors as moderators for the effectiveness of the three-stage breathing intervention on participants' response accuracy during cued go/no-go task. Overall, it was expected that a participant's ability to physiological self-regulate through alteration of respiratory parameters would systematically influence her/his performance on the cued go/no-go task.

Chapter Two: Methods

Participants

Forty male and forty female undergraduate students from the University of Kentucky between the ages of 18-27 were included in the study. Exclusion criteria included students who had medical conditions such as asthma, high blood pressure, gastrointestinal disorders, or neurological disorders such as ADHD. Participants were assigned randomly using a table of random numbers to either the experimental diaphragmatic breathing condition (424) or to the situational awareness control condition (32). A total of twenty males and females were assigned to each of the two breathing conditions. They were given a series of questionnaires, connected to physiological recording equipment, trained on a breathing technique according to condition, and then asked to complete a computerized cued go/no-go task to evaluate their ability to behaviorally self-regulate their inhibitory control system.

Power Analyses

An a priori power analysis was done with G*Power software to calculate the necessary sample size for a means difference analyses on the independent groups design selected for this study (Faul, Erdfelder, Buchner, & Lang, 2009). After reviewing previous research in the field, the effect size for the study was determined to be medium to large (Russell et al., unpublished results; Carlson, et al. 2001). Power of 80% was determined to be acceptable and with the model predictors (i.e. overall model) a sample size of 76 participants allows for an 80% power with an α=0.05. Therefore, a sample size of 80 yielded adequate power for analyses and accounts for the possibility of lost data.

Materials

Demographic Information. Participants provided their age, year in school, and ethnicity.

Self-efficacy. A self-efficacy form was used following the demographic form and again after completion of the cued go/no-go task. The measures were used to assess participants' confidence on controlling or identifying their body's physiological reactions during the experiment. Participants were asked to answer 10-items on a 1-7 Likert type scale. Questions such as, "How confident are you that you could successfully recognize the signs that you are hyperventilating (breathing too fast or deeply)?" were used to measure their self-confidence and self-awareness regarding their body's physiological state. In addition, questions such as, "When you complete the timed computer response task, how confident are you that you can effectively control your responses?" examined participants' self-confidence related to the cued go/no-go task.

Personal Drinking Habits Questionnaire (PDHQ). The PDHQ was administered after the self-efficacy scale and collected information about drinking habits and drinking history over three domains (Vogel-Sprott, 1992). The questionnaire obtained information about a participants' frequency of drinking (number of drinking occasions in a week), dose (milliliters of absolute alcohol per kilogram of body weight consumed in a typical drinking occasion), and duration (typical length in hours during a drinking occasion).

Alcohol Use Disorder Identification Test (AUDIT). The AUDIT was given following the PDHQ and assessed drinking behaviors and practices that are closely related to alcohol abuse. The questionnaire consists of 10 Likert type items with answers ranging from Never to 4+ times/week (Saunders et al., 1993). When developed by the

World Health Organization, it was found that 99% of known alcoholics scored an 8 or higher with only 3 of the non-drinking sample group scoring an 8 or more. The measure assesses four domains including: alcohol consumption, drinking behavior, adverse reactions, and alcohol related problems. The intra-scale Chonbach's α's was 0.88 for the US population sample.

Drug Use History Questionnaire (DUHQ). The DUHQ was added to measure the use of common stimulant and sedative drugs that might have affected study results. The DUHQ was administered following the AUDIT and participants were asked if they had used any of the listed drugs, the frequency of use in the last month, the quantity of dosage, and the method of administration.

UPPS-P. The UPPS-P was given following the DUHQ and measured personality dimensions of impulsivity across five subscales: Urgency, Premeditation (lack of), Positive Urgency, Sensation Seeking, and Perseverance (lack of). The measure uses 59 statements and a Likert type scale ranging from Strongly Agree/Agree Some to Disagree Some/Disagree Strongly. Each subscale produced internal consistency values between α=.82-.91 for the original four subscales and α=.94 for the recently added Positive Urgency scale (Cyders et al., 2007; Whiteside & Lynam, 2001).

Barrett Impulsivity Scale 11 (BIS-11). The BIS-11 was given after the UPPS-P and assessed the personality dimension of impulsivity with 30 self-report items such as "I buy things on impulse" or "I change jobs" (Patton & Stanford, 1995). The first order factors of the measure include constructs such as attention (lack of), motor impulsiveness, self-control (lack of), cognitive complexity (enjoyment level), perseverance (lack of), and cognitive stability. Participants' rated the 30 different statements on a 4-point Likert scale

ranging from Rarely/Never to Almost/Always on how representative each of the statements were. When developed, the BIS-11 had acceptable internal consistency with a college undergraduate population of α=.82. Factor inter-correlations were between the BIS-10 and the BIS-11 (r=.98, p<.0001) (Patton & Stanford, 1995).

Sensation Seeking Scales (SSS Form V). The SSS-V was administered following the BIS-11 and the measure assessed dimensions of sensation seeking personality traits such as Thrill and Adventure Seeking (α=.80), Experience Seeking (α=.75), Disinhibition (α=.80), and Boredom Susceptibility (α=.76). The questionnaire used 40 forced choice items to assess participant differences in stimulation need (Zuckerman, 2007; Zuckerman, 1996).

Heart Rate Variability (HRV). HRV tone is a physiological index that has demonstrated usefulness in providing a quantitative measure of sympathetic and parasympathetic activity, and an index of autonomic balance. We defined our measure of HRV between 0.15-0.40 Hz because that frequency range is commonly associated with parasympathetic tone. Also, measurement of cardiac functions within this range account for respiratory rate influences on HRV and can be referred to as respiratory sinus arrhythmia (RSA) (Berntson et al., 1997; Lehrer et al., 2010). Heart function was recorded with three Ag/AgCl electrodes using shielded leads connected to BioPac ECG100C electrocardiogram amplifier module. Sampling rate for heart function was set to 2000 samples/second. A Lead I configuration was used and sensors were attached in accord with standard laboratory protocol (Carlson et al., 2001).

Respiration Rate. Respiration rates were recorded using the BSL-SS5LB respiratory effort transducer and amplifier module for the BioPac MP100 system. The

respiration sensor was placed around the abdomen just below the rib cage and right above the navel. Respiration rates were recorded as breaths per minute.

Design

The experiment was constructed as a between-subjects design with equal numbers of males and females in each condition. We examined the differences between the two breathing conditions and investigated potential gender differences. The study trained experimental participants to breathe according to a three-stage breathing cycle (inhale-exhale-rest), at a pace of six breaths a minute, with diaphragmatic breathing mechanics. Participants in the control condition were trained to breathe according to a two-stage breathing cycle (inhale-exhale) at a pace of 12 breaths a minute, without any specific instructions on diaphragmatic mechanics. Twelve breaths a minute was chosen because it is both twice the rate of the three-stage breathing cycle condition, in addition, it is often considered the average breathing rate for individuals (Fried & Grimaldi, 1993). Participants were given a packet of questionnaires including demographics, self-efficacy, PDHQ, DUHQ, AUDIT, UPPS-P, BIS-11, and the SSS-V. Other than the initial questionnaires, the experimental procedures were conducted with an in-room computer. There was no deception in the study.

Procedure

University of Kentucky undergraduates were used to test the effects of increased physiological self-regulation through paced diaphragmatic breathing on a cognitive task that measured behavioral self-regulation or impulse control. Research participants were volunteers from undergraduate psychology classes recruited via the SONA online sign-up website. For participation, students received 1.5 hours of class research credit.

The brief study description ran as follows: "Undergraduates between the ages of 18-27 years are invited to participate in a project entitled, *The Effects of Paced Diaphragmatic Breathing on Cognitive Functioning.* The project will study how training in self-control procedures influences a person's cognitive functioning. Exclusion criteria include undergraduates who have medical conditions such as asthma, high blood pressure, gastrointestinal disorders, or neurological disorders such as ADHD. The study requires 1.5 hours of time to complete."

Participants who signed up for the study were emailed a reminder of their appointment and the requirements to abstain from eating, drinking alcohol, or tobacco use at least an hour before their scheduled appointment. Upon arrival participants were given the informed consent sheet that explained the procedure, available resources, and compensation for their involvement. All participants were asked if they followed directions on abstaining from food, alcohol, or tobacco products at least an hour before the appointment. If they failed to do so, they were asked to reschedule the appointment for another day. Participants who followed directions were seated in a comfortable chair. Before proceeding, the researcher also allowed participants to ask questions and spent time responding to any concerns. When all questions were answered to the satisfaction of the participant and the informed consent was signed, the study procedures began. The researcher explained to the participant that at any point in time if they felt discomfort or uneasy in any way, they could stop the study without facing penalty. All research procedures were approved by the University of Kentucky Committee for the Protection of Human Participants.

Participants completed the Demographic forms, Self-Efficacy scale, PDHQ, DUHQ, AUDIT, UPPS-P, BIS-11, and the SSS-V. After receiving permission, lab assistants attached physiological sensors to participants in accord with standard clinical protocol (Carlson et al., 2001). Then, a 5-minute baseline assessment was taken of physiological measures including breathing rate, heart rate, and HRV tone.

The experimenter explained to participants that they would be given instructions on a breathing pattern, be asked to demonstrate the pattern correctly, and then be asked to perform it during a 15 minute cued go/no-go task. Participants randomly received either the experimental breathing protocol or the control condition breathing protocol. The experimental condition was instructed to breathe at a rate of six breaths a minute and follow a three stage respiration pattern of inhale-exhale-rest at a pace of 4 seconds-2 seconds-4 seconds (424) with diaphragmatic breathing mechanics. The control condition was instructed to breathe at 12 breaths a minute and follow a two stage respiration pattern of inhale-exhale at a pace of 3 seconds-2 seconds (32) without specific direction to use diaphragmatic mechanics. Before beginning the cued go/no-go trial, participants were given an opportunity to ask questions and practice their breathing pattern for five minutes. An in-room computer delivered the breathing instructions for both conditions. The same computer was also used to present a visual aid to help participants pace their breathing rate during the minute training session. The visual cue consisted of an oval that expands, contracts, and remains still in according to the breathing condition's specified rate. Also, the breathing video included a soft tone that corresponded to the inhalation period and preceded the oval beginning to expand. The breathing rationale and description for each condition are reproduced below.

Breathing rationale for diaphragmatic group.

We are very interested in understanding your responses to the study procedures. Breathing so that the stomach is moving in and out rather than breathing with your chest can help relax you. This stomach breathing, or diaphragmatic breathing, can help you relax and maintain calmness in today's study experience.

Protocol for 424 breathing pattern.

Please remember the rule: you should do nothing to increase your sense of discomfort while you are practicing the breathing. To start breathing with your stomach, or diaphragm, you should rest in a comfortable position with your head centered, supported and in the midline of your body; your eyes are closed, with smooth eyelids; and smooth forehead; your mouth is relaxed: with lips apart, teeth apart, and tongue relaxed; there's no throat movement; your shoulders are sloped and even; elbows bent; your hands will be in a curled, relaxed position, not touching one another; knees are apart; and feet are pointing away from one another at a 45-90 degree angle. Then, place your right hand just below your rib cage on top of your stomach. Just exhale first to release air from your body—it should be a complete, relaxed release where there is no holding, controlling, or forcing of the release—it is like a balloon collapsing as you let your air go from your body. When you are ready to take your next breath of air in; let the stomach gently rise as if you are pushing your stomach up with the column of air coming in. After you take in a comfortable, normal breath,

release your muscles and let the air go just as you did at first when you started the exercise...there is no controlled, gradual release, just let go all at once and have the air move naturally out of your body. Then, pause and rest for a few moments before you take air in again to start another breath cycle. The rest period between breaths is the deepest point of your relaxation when everything is quiet and you relax before taking air in again. (Pause for 10 seconds) From the beginning of this training, you should breathe at a pace that makes you feel comfortable. (Pause for five seconds) You also want to breathe naturally and not too deeply in order to avoid over breathing or hyperventilation. If you were to feel light-headed or dizzy, chances are you are taking in too much air with each breath…take a little less air in on your next breath and the breaths that follow. (Pause 10 seconds) Most people find that counting to four while air is coming into your lungs may set a natural, relaxed pace. Once the air is released, the rest period is typically the time it takes to count from one to four. So, a starting pace for you can be counted as "air in-2-3-4; release; and rest-2-3-4." (Repeat this phrasing two times) Repeat this breathing pattern for several minutes to establish a comfortable, relaxed rhythm to your breathing. (Pause for five seconds) Let your stomach rise as air enters, then let the stomach fall as you release the air, and let everything rest until taking in your next breath of air. (Pause for 10 seconds) Your breathing rate will likely be somewhere between 5-6 breaths per minute as you practice diaphragmatic breathing. Let your breathing be slow and

relaxed as your stomach moves up and down. Please use this diaphragmatic breathing method throughout your remaining time in the laboratory.

Control rationale.

We are very interested in understanding your responses to the study procedures. Since we all have our own ways of responding to what happens to us, we are interested in following your responses carefully. The purpose of our project is to better understand the ways in which individuals such as yourself respond to the application of the laboratory procedures.

Control protocol.

First of all, it is important to remember the rule that you should do nothing to increase your sense of discomfort. Take a few moments to notice your surroundings and let yourself get comfortable and settle in. We would like for you to sit quietly during the procedure and let your attention be directed to the activities going on around you. You should be observing yourself and your environment as you undergo the laboratory experience. Please remain aware of your surroundings and what is happening at any given moment. Take a few minutes now to let yourself be aware of what is happening. (Pause for five seconds) Next, we would like you to focus on the pace of your breathing. To start breathing, you should rest in a comfortable position. Just exhale first to release air from your body. When you are ready to take your next breath of air in; let the lungs fill as you

count to three. After you take in a breath, let the air go just as you did at first when you started the exercise. From the beginning of this training, you should breathe at a pace that makes you feel comfortable. (Pause for five seconds) You also want to breathe naturally and not too deeply in order to avoid over breathing or hyperventilation. If you were to feel light-headed or dizzy, chances are you are taking in too much air with each breath…take a little less air in on your next breath and the breaths that follow. (Pause 10 seconds) Most people find that counting to 3 while air is coming into your lungs may set a natural, relaxed pace. Then, once the air is released, you begin the next breath cycle. So, a starting pace for you can be counted as "air in-2-3 and release." (Repeat this phrasing two times, read "release" slowly) Repeat this breathing pattern for several minutes to establish a comfortable, relaxed rhythm to your breathing. (Pause for five seconds) Your breathing rate will likely be somewhere between 12-14 breaths per minute as you practice. We will want you to use this breathing pace and let yourself be aware of what is happening around you throughout your remaining time in the laboratory.

Cued Go/no-go Task. The cued go/no-go task was delivered through an in room computer using E-Prime experiment generation software (Schneider, Eschman, & Zuccolotto, 2002). Each cued go/no-go trial followed this order: (1) the appearance of a fixation point (+); (2) a blank white screen for 500 ms; (3) a cue image, presented for one of five stimulus onset asynchronies (SOAs= 100, 200, 300, 400, and 500ms); (4) a Go or

No-go target, which remained on the screen until a participant response was entered or 1,000 ms elapsed; and (5) a brief intertrial interval of 700ms.

The cue image was a rectangle (7.5cm X 2.5 cm) framed by a 0.8mm black outline. The cue was presented in the center of the computer screen against a completely white background. Each cue image was presented in either a vertical (7.5cm X 2.5 cm) or horizontal (2.5 cm X 7.5 cm) orientation for one of five SOAs. The Go (color green) and No-go (color blue) targets were used to fill the interior of the outlined rectangle cue. Participants were instructed to respond or press the (/) key on the computer's keyboard if the cue filled in with the target color green. If the rectangle cue filled in with the target color blue they were to suppress their response (not press any key). Keyboard presses were made with the participants' index finger of their dominant hand. It is important to note that the target colors were presented in hues that were easily distinguished by all participants.

The cue image orientation (vertical or horizontal) signaled the probability that a Go or No-go target would be displayed. Vertically oriented cues preceded the presentation of Go targets (green rectangle) on 80% of the trials and No-go targets (blue rectangle) on 20% of the trials. Horizontally oriented cues preceded No-go targets 80% of the time and Go targets on 20% of the trials. The frequency of cue-target image pairings allowed the vertically and horizontally oriented rectangles to function as Go and No-go cues, respectively. The SOAs ensured that participants remained focused on the presentation of each new cue and prevented participants from anticipating the time lapse between cue and target presentation. A complete cued go/no-go test consisted of 250 individual trials with an equal number of the vertical (125) and horizontal (125) rectangle

cues. In addition, a complete cued go/no-go test included an equal number of Go (125) and No-go (125) target trials, with green and blue rectangles serving as the targets respectively. For each trial, the computer recorded whether a response occurred and the reaction time in milliseconds for that response.

The cued go/no-go task was used to evaluate participants' ability to inhibit impulses and behaviorally self-regulate. For the present study, analyses focused on Go cues with No-go targets. In particular, we were interested in participants' accuracy during a Go cue and No-go target pairing. The preparatory processing that occurs following a Go cue initiates a behavioral response (pressing the (/) key) that must be inhibited when a No-go target is presented. Participant accuracy during these trial pairs served as the main dependent variable and is referred to as Inhibitory Trials. Participant response accuracy for No-go cues and No-go targets was also examined and referred to as No-go Paired Trials. During trials including Go targets and either Go cues or No-go cues, participants' speed of reaction in milliseconds was measured to examine potential effects of the breathing intervention on the speed of participant responding (pressing the (/) key).

Debriefing.

The debriefing started with the research assistant asking, "Do you have any questions about the experience?" This was followed with, "Do you feel OK about leaving at this time?" If there were no further questions and the participant was OK with leaving, they were excused from the study. With any additional concerns about leaving, the research assistant was instructed to explore them and if necessary provide the participant with the phone number for the University Health Services (859-323-5823). Then, the participant was excused from the study.

Analytic Strategy

First, data were checked for normality, independence, and homogeneity. Once it was determined that data met the appropriate parameters, independent samples *t*-tests were performed to identify whether significant baseline differences existed between breathing conditions. For the UPPS-P, BIS, and AUDIT the data violated the assumption of homogeneity and efforts were made to transform the variables, but attempts at normalizing the distributions were not successful. Therefore, one-way ANOVA's were used to investigate potential differences between breathing conditions for those baseline variables because ANOVA offers some protection against violations of homogeneity of variance (Cohen, Cohen, West, & Aiken, 2013). Following investigation of baseline differences, the ability of the current breathing entrainment protocol to alter participants' physiological measures linked to behavioral self-regulation was evaluated. A marginally significant (p=0.03) baseline difference existed between the two breathing conditions with participants in the 424 breathing condition scoring slightly higher on the self-efficacy than participants in the 32 breathing condition. Initial analyses were completed controlling for this baseline difference with ANCOVA analyses. Secondary analyses found that no significant differences existed between the use of ANCOVA (controlling for baseline self-efficacy) and ANOVA analyses. Therefore, it was decided to report only ANOVA analyses. Within each breathing condition, paired samples *t*-tests were used to investigate changes in the physiological measures from baseline values to levels during the cued go/no-go task.

Once the efficacy of the breathing protocol was established, a 2x2 (gender x breathing condition) ANOVA accounting for a baseline self-efficacy effect was used to

investigate potential differences between gender and breathing conditions on participants' mean accuracy through the Inhibitory Trials. Multiple hierarchical regression analyses were used to probe for potential moderating effects of impulsivity, sensation seeking, and drinking behavior on the relationship between physiological self-regulation (HRV tone) and participants' behavioral self-regulation or their mean accuracy over the Inhibitory Trials. Standardized units were calculated for all continuous variables before conducting moderation analyses to control for collinearity. The regression model incorporated the standardized variables into individual blocks beginning with participants' HRV tone during the cued go/no-go task, the AUDIT questionnaire, and ending with the interaction term of HRV tone and the AUDIT questionnaire. The process was repeated for each questionnaire.

An exploratory 2 (gender) x2 (breathing condition) ANOVA was used to investigate breathing protocol effects on participants' mean response times for trials involving Go targets and either the Go or the No-go cues. The same 2x2 ANOVA was also used to explore potential effects of the breathing protocol on participants' mean accuracy for trials pairing No-go cues and No-go targets referred to as No-go Paired Trials. A standard alpha level of 0.05 was used for all statistical analyses. No data were transformed or omitted. All analyses were performed using SPSS 22.

Chapter Three: Results

Baseline Statistics

Baseline Self-efficacy scores were significantly different between breathing conditions, $t(78)=2.15$, $p<.05$. No significant differences between groups were found on demographic variables of age, $t(78)=0.09$, $p>.05$, or education, $t(78)=1.21$, $p>.05$. No significant differences between conditions were found for the DUHQ, $t(46)=0.00$, $p>.05$. On the SSS-V scale of sensation seeking, no significant differences between groups were found, $t(78)=1.02$, $p>.05$. One-way ANOVAs suggested no significant differences existed between breathing groups on the overall measure from the UPPS-P, $F(1,78)= 0.004$, $p>0.05$, or its subscales of Negative Urgency, $F(1,78)= 0.25$, $p>.05$, Premeditation (Lack), $F(1,78)= 0.004$, $p>0.05$, Perseverance (Lack), $F(1,78)= 0.53$, $p>0.05$, Sensation Seeking, $F(1,78)= 0.29$, $p>0.05$, and Positive Urgency $F(1,78)= 0.21$, $p>0.05$. No significant differences between conditions were found on the BIS, $F(1,78)= 0.008$, $p>0.05$, or the AUDIT, $F(1,78)= 2.25$, $p>0.05$. Please see Table 1 for group means and additional information for each of the baseline demographic questionnaires and measures. Similarly, no differences were found between breathing conditions on all three physiological baseline measures of breathing rate, $t(77)=0.76$, $p>.05$, heart rate, $t(77)=0.34$, $p>.05$, and HRV tone, $t(77)=0.48$, $p>.05$. For means and standard deviations for physiological baseline measures please see Table 2.

Manipulation Check

To explore how the breathing entrainment protocol influenced outcomes, paired samples *t-tests* were used to investigate the differences between baseline levels of breathing rate, heart rate, and HRV tone and the levels recorded during the cued go/no-go

task portion of the experiment. Within the 424 breathing condition, significant differences were found between the baseline and cued go/no-go task levels of breathing rate and HRV tone, $t(39)=5.99$, $p<.001$; $t(39)=3.21$, $p<.01$, respectively. However, no difference in the heart rate of the 424 breathing condition was found, $t(39)=0.7$, $p> 0.05$. Additionally, no differences were found between the 32 breathing condition's baseline and cued go/no-go task measurements on heart rate, $p=0.27$, breathing rate, $p=0.19$, and HRV tone, $p=0.99$. Please see Table 2 for means and standard deviations of physiological measures.

Inhibitory Trial and No-go Paired Trial Response Accuracy

A 2(gender) x2 (breathing condition) ANOVA investigated participants' accuracy during the trials pairing Go cues with No-go targets (Inhibitory Trials) and revealed no differences for gender or the interaction terms, $F(1,76)= 0.02$, $p>0.05$ and $F(1,76)= 0.79$, $p>0.05$, respectively. Participants in the 424 breathing condition, however, performed significantly better on the Inhibitory Trials than participants in the 32 breathing condition, $F(1,76)= 5.61$, $p=0.02$, Cohen's $d=0.54$

A 2(gender) x2 (breathing condition) ANOVA was also used to investigate participants' accuracy on trials pairing No-go cues and No-go targets (No-go Paired Trials). Results indicated that both gender and the interaction term did not significantly predict participants' accuracy on the No-go Paired Trials, $F(1,76)= 0.01$, $p>0.05$ and $F(1,76)= 0.23$, $p>0.05$, respectively. Although breathing condition did not meet criteria for significance, results suggest that breathing condition may be trending toward affecting participants' accuracy on the No-go Paired Trials, $F(1,76)= 2.07$, $p=0.16$. For means and standard deviations please see Table 3.

Go Target Trial Reaction Times

A 2(gender) x2 (breathing condition) ANOVA investigated participants' mean reaction times during trials consisting of Go targets (requiring a response) and either No-go cues or Go cues. For No-go cues, gender, breathing condition, and the interaction of these variables were not found to effect significantly participants' mean reaction times, $F(1,76)= 0.63$, $p>0.05$; $F(1,76)= 0.02$, $p>0.05$; $F(1,76)= 0.08$, $p>0.05$, respectively. In addition, gender, breathing condition, and the interaction of these variables were not found to significantly effect participants' mean reaction times on Go cue trials, $F(1,75)= 1.06$, $p>0.05$; $F(1,75)= 0.4$, $p>0.05$; $F(1,75)= 0.22$, $p>0.05$, respectively. For means and standard deviations please see Table 3.

Moderation of No-go Response Accuracy

Our hypotheses highlighted the importance of testing the UPPS-P, BIS, SSS, and AUDIT for their potential moderation of relationship between self-regulation (HRV tone) and participants' response accuracy for the No-go trials. Each questionnaire was first converted to standardized units and then tested within a separate hierarchical regression model. The regression analyses suggested no significant moderation existed for UPPS-P, $F(1,77)= 1.55$, $p>0.05$, BIS, $F(1,77)= 1.72$, $p>0.05$, SSS, $F(1,77)= 2.1$, $p>0.05$, or the AUDIT, $F(1,77)= 2.2$, $p>0.05$.

Table 3.1. Baseline Group Differences

	424 Condition		32 Condition	
	Mean	s.d.	Mean	s.d.
Age	19.5	0.18	19.55	0.52
Education	1.85	0.17	1.6	0.12
Baseline-SE	5.0*	0.62	4.62*	0.91
Post-SE	5.58	0.69	5.37	1.13
UPPS-P	123.48	19.71	123.18	20.78
$UPPS\text{-}P_{Negative\ Urgency}$	25.0	6.96	25.75	6.4
$UPPS\text{-}P_{Lack\ Premeditation}$	21.01	5.15	20.9	5.02
$UPPS\text{-}P_{Lack\ Perseverance}$	17.65	4.41	18.38	4.49
$UPPS\text{-}P_{Sensation\ Seeking}$	35.93	7.39	34.98	8.27
$UPPS\text{-}P_{Positive\ Urgency}$	23.85	7.7	23.1	6.95
BIS	71.4	8.49	71.58	8.6
SSS	18.35	6.03	19.85	7.14
AUDIT	4.33	3.89	5.7	4.3
DUHQ	0.67	0.76	0.67	0.82

Note. Self-Efficacy (SE). Alcohol Use Disorders Identification Test (AUDIT). Drug Use History Questionnaire (DUHQ). Barret Impulsivity Scale (BIS). Zuckermann Sensation Seeking Scales (SSS). Heart rate (HR). Breaths per minute (BPM). Heart Rate Variability (HRV). Standard deviation (s.d.).

*Group difference significant at $p < 0.05$ level.

Table 3.2. Physiological Recordings

	Baseline (s.d.)		Training (s.d.)		Cued Go/No-go Task (s.d.)		Post Baseline (s.d.)	
	424	32	424	32	424	32	424	32
BPM	12.69 (3.69)	12.94 (3.44)	5.76*** (0.91)	14.0*** (1.66)	9.2*** (3.29)	13.82*** (2.7)	10.03** (4.33)	12.17** (2.92)
HR	73.61 (11.63)	76.12 (11.53)	72.58 (9.71)	76.18 (10.52)	74.15 (10.6)	74.71 (9.7)	72.84 (10.63)	72.48 (10.35)
HRV	6.97 (1.11)	6.77 (1.26)	7.1* (1.08)	6.6* (1.18)	7.33** (0.83)	6.77** (1.1)	7.26 (1.09)	6.98 (1.15)

Note. Breaths per minute (BPM). Heart rate (HR). Heart Rate Variability (HRV).

Standard deviation (s.d.).

*Tending towards significance p=0.052

**Group difference significant at $p < 0.05$ level.

*** Group difference significant at $p < 0.001$ level

Table 3.3. Cued Go/no-go Task Accuracy and Reaction Times

	Inhibitory Trial Accuracy (s.d.)		No-go Paired Trial Accuracy (s.d.)		No-go Cue RT (s.d.)		Go Cue RT (s.d.)	
	424	32	424	32	424	32	424	32
	0.99	0.98	0.98	0.96	356.29	352.74	343.8	348.48
Males	(0.01)	(0.02)	(0.03)	(0.05)	(38.0)	(36.28)	(29.55)	(35.42)
	0.99	0.98	0.97	0.96	347.46	348.48	339.86	338.02
Females	(0.01)	(0.02)	(0.06)	(0.05)	(32.55)	(40.1)	(27.25)	(32.43)
Condition	0.99*	0.98*	0.98	0.96	351.87	350.61	341.83	343.25
Totals	(0.01)	(0.02)	(0.05)	(0.05)	(35.21)	(37.8)	(28.13)	(33.88)

Chapter Four: Discussion

The study was designed to assess the role of breathing training for increasing participants' markers of physiological self-regulation (HRV tone) from resting levels and to demonstrate improved behavioral self-regulatory capacity in participants' mean accuracy scores on a task requiring inhibitory control. In addition, the effects of impulsivity, sensation seeking, and drinking behaviors were examined as possible moderators between self-regulation and improved performance on the cued go/no-go task. Because controlling for the baseline difference on the two breathing condition's self-efficacy scores did not yield different results, the baseline difference was not controlled for in final analyses.

Results suggested the 424 breathing condition improved the physiological markers of self-regulation (slower breathing rate and increased HRV tone) from baseline, while no changes were found for the 32 breathing condition's physiological indices. Moreover, the 424 condition showed significantly higher HRV tone and lower respiration rates during training and during the cued go/no-go task as compared to the 32 condition. These findings indicate that there were reliable changes in physiological parameters with exposure to the 424 breathing protocol and that expectancy effects did not account for recorded differences. These outcomes are consistent with previous literature (Jerath et al, 2006; Lehrer et al., 2000; Lehrer et al., 2010; Russell et al., unpublished results). Additionally, participants in the 424 condition outperformed the 32 condition on the Inhibitory Trials of the cued go/no-go task (Go cue and No-go target). These findings suggest the use of a short (six minute) breathing modification protocol allows individuals voluntarily to increase HRV tone and decrease respiration rates from resting levels,

thereby improving outcomes for tasks involving both behavioral and physiological self-regulatory systems (Carlson et al., 2001; Russell et al., unpublished results; Russell et al., 2014). Although the primary hypotheses were supported, results did not support moderation models involving impulsivity, sensation seeking, and drinking behaviors.

The cued go/no-go task has been considered a valid assessment of inhibitory control systems in a wide array of research studies (Fillmore et al., 2009; Marczinski & Fillmore, 2003; Neubert, Mars, & Rushworth, 2013). The present results supported the a-priori hypothesis that altering breathing via a paced diaphragmatic breathing protocol would significantly affect accuracy on the inhibitory portion of the cued go/no-go task. The present finding is consistent with Thayer's et al., (2009) work that suggested ventrolateral prefrontal cortex activity or specifically the inferior frontal gyrus, thought to be the center of inhibitory control, may be modulated through vagal pathways that can be influenced by voluntary breathing entrainment (Neubert et al., 2013). Although the precise mechanisms for how breathing entrainment influences inhibitory control may not be entirely understood, the pervading theory posits that connections between cardiac functions, allocation of oxygenated blood, and cognitive control structures may be involved in prefrontal processes involved with inhibitory control (Porges, 2007; Thayer & Lane, 2009). Without neural imaging to explore this model in the present study, however, it is not possible to determine what specific neural mechanisms may be involved in the increase of inhibitory control when breathing parameters are altered. Although previous research has demonstrated the potential links between physiological self-regulation, as measured by HRV tone, and behavioral self-regulation measured as inhibitory control processes, the present study is among the first to demonstrate

manipulation of inhibitory control via voluntary alterations in breathing parameters (Denver et al., 2007; Elliot et al., 2011; Lehrer et al., 2010; Vaschillo et al., 2008; Mun et al., 2008). The ability of the breathing protocol to create a significant improvement in inhibitory control over the 15-minute long cued go/no-go task after only six minutes of training suggests the protocol's effect may portend the possibility of achieving a clinically significant effect in other spheres involving self regulatory processes (Jacobson & Truax, 1991). Further studies exploring this question are needed.

The present study did not support the a-priori moderation models that predicted participants who scored high on measures of impulsivity or sensation seeking would perform more poorly on the cued go/no-go task than participants not categorized as high on either personality trait. In addition, drinking behaviors were not found to moderate the relationship between self-regulation and cued go/no-go task accuracy. One potential explanation for the lack of moderation effects in the present study is that the sample did not include individuals who would score high enough on the measures of the personality variables to influence significantly the observed relationship between self-regulation and inhibitory control. With regards to the lack of moderation by drinking behaviors, this again may be in part due to restricted range of the sample used in the study. Therefore, in any future attempts to investigate the role of these variables in the self-regulation and inhibition paradigm, it may be important to pre-screen participants to ensure a broader range of individuals would be included in the sample.

It is important to note the difference in mean accuracy levels between the Inhibitory Trials and the No-go Paired Trials. In previous literature, mean accuracy levels are often higher in No-go Paired Trials as opposed to the Inhibitory Control Trials

(Marczinski & Fillmore, 2003). Although the present findings are not consistent with previous literature, there are several possible explanations. First, on both the Inhibitory Trials and the No-go Paired Trials participant accuracy rates were as high or higher than previous research (Fillmore et al., 2009; Marczinski & Fillmore, 2003). With response accuracy ranging between 96-99%, it is possible that a ceiling effect was operating. In addition, for the Go target trials with either Go or No-go cues, participant reaction times in both breathing conditions were slower than in previous literature (Fillmore et al., 2009; Marczinski & Fillmore, 2003). This may be a consequence of participants concentrating on their breathing while completing the cued go/no-go task. The combination of these two factors may account for the unexpected result of higher accuracy on Inhibitory Trials than No-go Paired Trials. Potential explanations for the higher accuracy and the influences of increased attentional demands during the cued go/no-go task should be examined in future work.

Although the present study supported the continued exploration of breathing interventions for improved cognitive functioning, the replication of these findings in other laboratories and with other cognitive tasks is needed. The sample consisted of predominately 18-19 year old college students without major health concerns; further study is needed with broader samples and with individuals who might be prone to problems with exercising inhibitory control, e.g., persons prone to excessive alcohol consumption or gambling. The ability of the breathing protocol to safely and effectively alter breathing rates and subsequently HRV tone within clinical populations is an important next step in exploring the potential utility of the current protocol. Second, it is important to consider that the authors decided not to take into account breathing period

and depth as covariates when using RSA as an index of HRV. Although there are several arguments for the removal of respiratory parameters, we believe that the amplitude of RSA is indexed by tonic vagal cardiac tone and can be accurately measured (Donchin, Feld, & Porges, 1985; Pagani et al., 1986; McCabe, Yongue, Ackles, & Porges, 1985; ŽEmaitytė, Varoneckas, & Sokolov, 1984a, 1984b). We acknowledge that significant arguments have been raised about this analytic approach, but until conclusive evidence can be given that respiration induced variance in RSA is a direct result of inspiratory and expiratory phasic changes in vagal heart tone, we believe the results presented are robust (Eckberg, 1983; Grossman, 1983; Grossman & Svebak, 1987; Grossman, Karemaker, & Wieling, 1991).

Inhibition has been defined as a diverse set of controls over behavioral impulses. Understandably, there exist a wide array of inhibitory control tasks that attempt to measure these potentially independent components of inhibition and the different cognitive circuits involved with each (Neubert et al., 2013; Reynolds, Ortengren, Richards, & de Wit, 2006). Therefore, although the present breathing protocol was successful in altering one domain of accuracy on the cued go/no-go task, future research must consider exploring whether breathing alterations influence different aspects of inhibition or are limited to influencing only the cued go/no-go task.

The present results support the notion that HRV tone is related to increased ability to inhibit primed behavioral responses on cued go/no-go tasks. Since the objective of breathing interventions is fostering improved self-regulatory capacity and thereby improved ability to respond appropriately to environmental demands, the outcomes from this project suggest further examination of behavioral interventions to deliberately alter

HRV might be useful when applied to problems associated with regulating emotional distress (e.g., depression, anxiety, stress), physiological disturbances requiring medical attention (e.g., hypertension, diabetes, elevated cholesterol, asthma, COPD, motion sickness), and disruptions in cognitive processing and attention control (e.g., impulse control and behavioral inhibition) (Elliot et al., 2011, Kulur, Haleagrahara, Adhikary, & P.S., 2008; Lehrer et al., 2006; Russell et al.,2014; Thayer & Lane, 2000; Thayer & Brosschot, 2005; Thayer & Lane, 2009; Thayer et al., 2009; Thayer, Loerbroks, & Sternberg, 2011; Thayer et al., 2012; Vaschillo et al., 2008). Future studies should explore the utility of modifying self-regulatory capacity in populations suffering from chronic self-regulatory failures. Studies demonstrating the utility of self-regulatory training protocols for these chronic conditions may provide new pathways by which those suffering from these conditions find the means to achieve better and longer lasting treatment outcomes.

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Russell, M. E. B., Hoffman, B., Stromberg, S., & Carlson, C. R. (2014). Use of controlled diaphragmatic breathing for the management of motion sickness in a virtual reality environment. *Applied psychophysiology and biofeedback*, *39*(3-4), 269-277.

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