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Does Breath Pattern Influence Reacting and Feeling?

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DOES BREATH PATTERN INFLUENCE REACTING AND FEELING?

by

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Dedication

To the people who gave me breath.

Gary & Diane Hazelton

To the air that I breathe.

Miles Herr

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Abstract

This experimental within-participant reversal paradigm quantified effects of breath manipulation on emotional reactivity and inhibition. Participants were assessed for inhibitory ability and emotional reactivity at baseline and following three breathing conditions: controlled neutral, resonance frequency, and variable breathing; selected to assess a range of breathing behavior from anxious breathing, vegetative breathing, and meditative breathing. Emotional reactivity was elicited using the International Affective Picture System and inhibition utilizing a verbal Stop Signal task. Dependent variables for emotion induction included self-reported mood and arousal using the Self-Assessment Manikin of Valence and Arousal, and for inhibition was response time and accuracy. For twenty-six healthy participants, emotion induction demonstrated no statistical findings across breathing condition. However, for inhibition tasks, a significant reduction in inhibitory response time and increase in response accuracy was found following resonance frequency breathing. Breath manipulation effects inhibitory control and could be a tool for improving efficacy of behavioral therapies addressing aspects of inhibition.

Keywords: COGNITION, INHIBITION, EMOTION, BREATH, RESONANCE FREQUENCY BREATHING

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Introduction

Throughout human existence, breath has been a cornerstone of human fascination. Through centuries of art, folklore, and traditions like yoga, humans have marveled at and harnessed the power of breath pattern manipulation (Nestor, 2020; Pressman, 1993). For some traditions, such as yoga, the importance of breath manipulation is clear. The earliest textbook on yoga, the Yoga Sutras, was written by Patanjali in the second century BCE. The text defines the traditional Ashtanga ("eight-limbed") Yoga tradition, in which there is a sequence of eight observances, which are to be mastered in order with the ultimate goal of yoking the mind with the body (Patañjali, 2019). The fourth limb is breath regulation. In Sanskrit, (the primary language of yoga,) the word for breath regulation is *prâñâyâma*. It is a combination of the root words *prâñasya*, meaning life force, and *yama,* meaning external discipline. Breath regulation may be achieved through the practice of specific breath patterns or mantra chanting. In essence, yogic gurus have understood for thousands of years that harnessing breath is an essential prerequisite for mind-body unity.

Breath manipulation is not unique to yoga. Similar breath manipulation practices can be seen through mantra-like prayers and chanting in other ancient traditions and religions such as Christianity, Buddhism, Hinduism, Jainism, and Islam (McKim, 2016). In a study on the effects religious chanting on brain responses to fear and stress, Gao et al. (2017) concluded that religious chanting had effects on late-stage emotional and cognitive processing. While Gao et al. (2017) do not hypothesize what mechanisms may be driving these effects, other authors believe it may be due to breath manipulation. Bernardi et al. (2001) explored the effects of the reciting the Ave Maria portion of the Rosary prayer and yogic mantras on heart rate variability and baroreflex sensitivity, two mechanisms closely tied to respiration and other cognitive and emotional processes. They found that both recitations slowed the breath to approximately six breaths per minute and enhanced both heart rate variability and baroreflex sensitivity, two aspects which have been known to influence cognition (Forte et al., 2019). Similar effects have been found with poetry recitations (Cysarz et al., 2004).

Despite the rich history of breath manipulation practices throughout human existence, its use has fallen into obscurity in modern society, particularly mainstream medical practice (Nestor, 2020, p. xviii). The deleterious effects of dysfunctional breath patterns on physical and mental health are widely known in the medical field, but breath manipulation practices are greatly viewed as esoteric and rarely, if ever, recommended by Western medical providers (Peters, 2014). Breath patterns, their psychophysiological effects, and the directionality of such relationships have historically been difficult to measure, leading to a dearth of evidence to support or refute the use of breath manipulation practices to alleviate physical and psychological ailments. Excitingly, recent technological advances have made measurement of breath manipulation and its related effects more accessible (Lorig, 2016). Initial research into certain types of breath patterns, such as resonance frequency breathing, which echoes patterns of religious chanting, have shown notable positive influences on systems such as the nervous and cardiovascular systems (Laborde, Allen, Borges, Iskra, et al., 2022; Leganes-Fonteneau et al., 2021; Paccione & Jacobsen, 2019; Petta, 2017; Price et al., 2022; Steffen et al., 2017). Further research into the relationships between breath patterns and psychophysiological systems holds great promise for supporting the efficacy of existing rehabilitative treatment protocols.

Breath is free, readily accessible and, if history is to be believed, an extremely powerful tool for altering physical and mental state, healing, and ultimately creating a cohesive bond between the mind and body.

Literature Review

Respiratory Physiology

The primary purpose of respiration is to provide oxygen to and remove waste from the body. This is achieved by a tightly coupled interaction between the respiratory and cardiovascular systems, together referred to as the cardiopulmonary system, which are ultimately controlled by the nervous system (Gordan et al., 2015). Due to the tightly coupled interactions of respiration with these two vital systems (cardiovascular and nervous), respiration has either direct or indirect interactions with most of the other systems in the body, and therefore, has the potential to affect multiple aspects of body functioning simultaneously (Bordoni & Zanier, 2013; D. Bradley, 2014).

Ventilation and Perfusion

Respiration is roughly comprised of two components: ventilation and perfusion. Ventilation is the mechanical aspect of respiration and refers to the physical act of moving air into (inhalation) and out of (exhalation) the lungs (Seikel et al., 2010, p. 135). Ventilation is achieved by the activation of respiratory muscles to alter the volume, and therefore pressure, within the thoracic cavity. These pressure changes allow for air to flow between the atmosphere and our respiratory cavities. The muscles primarily involved in ventilation include the diaphragm, internal intercostals, external intercostals, and abdominals. However, accessory muscles of respiration, which provide assistance and structural support, may also be involved, depending on a variety of factors. Ventilation can be controlled automatically via pattern generators in the brain stem, or volitionally through interactions of cortical structures (West, 2012, pp. 126–128).

Perfusion refers to the saturation of a tissue, such as blood, with a fluid, such as oxygen or carbon dioxide (Seikel et al., 2010, p. 135). In the respiratory system, this occurs at the level of the alveoli in the lungs (Seikel et al., 2010, p. 135). Perfusion is an integral respiration process which provides oxygen to and removes carbon dioxide and other waste from the cells. Once the blood is saturated with gasses, movement of the blood is achieved primarily by the circulatory system, which is solely under autonomic control (Berntson et al., 2017).

Control of Respiration

The processes of ventilation and perfusion rely heavily on one another to maintain respiratory homeostasis (Camillo & Nasr, 2014). When ventilation and perfusion are paired efficiently, or in other words, when the gasses being received and removed through breath movements match the metabolic need of the cells, there is a balanced proportion of oxygen to carbon dioxide in the blood. If metabolic needs increase, such as during vigorous exercise, ventilation, and subsequently perfusion, will increase, as well.

There is a large reserve of oxygen in the bloodstream at all times, making the alteration of CO_2 the primary route of affecting the blood's acidity, which must remain within a narrow homeostatic range at 7.4 pH (Gilbert, 2014a). Blood acidity can be affected by a few other physiologic mechanisms, but the quickest way to alter blood pH is through respiration changes. A mismatch in ventilation and perfusion parameters may result in conditions such as hyperventilation or hypoventilation, in which one is breathing in excess of or below metabolic need, respectively (Chaitow et al., 2014b). These mismatched states alter the proportion of oxygen to carbon dioxide in the blood, and subsequently the acidity of the blood, potentially resulting in respiratory alkalosis (high pH) or acidosis (low pH). Optimal body acidity is imperative for many foundational physiologic functions such as enzymatic activity, protein structure, and the activity and efficiency of ion channels and pumps (Anaizi, 2014).

Neural control of respiration relies greatly on these shifts in blood acidity, which are sensed by chemoreceptors located within the arterial walls (Lorig, 2016). When there is high CO2, acidity increases, and there is a higher drive to breathe. Conversely, when there is low CO2, acidity decreases, resulting in a lower drive to breathe (Gilbert, 2014a). In addition to chemoreceptors, stretch receptors located within the lungs provide sensory information to the respiratory control centers in the brainstem (West, 2012, pp. 132–133). These mechanisms allow for respiration to continue automatically and subconsciously. We can override automatic breathing to an extent by exerting conscious cortical control over respiratory muscles to volitionally alter ventilatory characteristics, which in turn affect perfusion (West, 2012, pp. 134–139). However, our nervous system will revert to automatic breathing if the volitional patterns differ too significantly from metabolic need. This reversion to automatic control may take the form of a gasp or, in extreme cases, a loss of consciousness.

Parameters of Respiration

Ventilatory characteristics, or breath parameters, can be defined though a number of physical and descriptive measures. Breath rate refers to the number of complete cycles of inhalation and exhalation per second. At times the duration of inhalation or exhalation is measured and can be calculated as the ratio of the length of inhalation to exhalation. Depth refers to the volume which one inhales or exhales within cycles, also known as the tidal lung capacity (Blows, 2001). Route and impedance are related and have to do with the path of the breath (i.e., nose or mouth) and any resistance to airflow created throughout the inhalation, exhalation, or both. Resistance may be created by a constriction at one or more regions of the upper respiratory tract, most commonly the glottis, soft palate, nares, or lips. Breath parameters can be altered individually (e.g., only changing rate) or in various combinations (e.g., changing rate, depth, route, and impedance). Each parameter can be viewed as a ventilatory behavior that has downstream physiological effects. For our purposes, we will refer to constellations of altered breath parameters as breath patterns.

Interactions Between Breath Pattern and Non-Respiratory Physiology

As previously mentioned, ventilatory behaviors, or breath parameters, can be altered volitionally or automatically to have downstream effects on other systems of the body (West, 2012). Additionally, breath patterns may be affected by factors outside of volitional or automatic control such as physical deformity, trauma, injury, environment, and more (Chaitow et al., 2014a). The parameters of breath (described above) may be altered in many permutations, creating a wide range of possible breath patterns with varying physiologic effects. These effects can be roughly categorized as visceral and somatic effects. Visceral physiological effects of breath pattern changes primarily affect the renal, cardiovascular, and nervous systems. Somatic effects refer to interactions between the nervous and somatic systems via a sensorimotor feedback loop.

Visceral Physiological Effects

Interactions of the respiratory system with the renal system primarily serve the purpose of mediating the acidity of the blood. As previously mentioned, blood must remain in a tight range of pH (around 7.4 pH) for optimal homeostatic functioning. Respiration is the quickest way we can alter blood pH. However, there are other mechanisms, such as the renal system. The kidneys may alter the pH of the blood by retaining bicarbonate, but this process may take several hours or even days (Gilbert, 2014a). If our breath pattern does not match our metabolic need and is unable to maintain the pH of our blood, as in cases of chronic hyper- or hypoventilation, the kidneys must work overtime to correct the pH levels. Symptoms of respiratory alkalosis or acidosis may include stimulation of the breathing reflex (as when holding the breath too long), light-headedness, weakness, and confusion (Gilbert, 2014a). Severe acidosis may result in a coma and severe alkalosis may result in death.

Body Rhythm Resonance: Interactions Between the Respiratory, Cardiovascular, and Nervous Systems

An interesting aspect of respiration is its oscillatory nature. Similarly, our cardiovascular and nervous systems rely on oscillatory mechanisms to function (Montano et al., 2001; Schnitzler & Gross, 2005). As with any oscillatory systems in nature, there are specific frequencies at which these systems oscillate most efficiently. This state is called resonance. The oscillations of respiration can enhance or impede the oscillations of the cardiovascular and nervous systems, depending on their frequency (Tonhajzerova et al., 2016). Additionally, respiratory oscillations have shown the ability to entrain neural and cardiovascular oscillations (Tort, Ponsel, et al., 2018).

Effects of respiration on the cardiovascular system are primarily measured in the form of heart rate variability (HRV). HRV refers to measure of the variation of inter-heartbeat intervals over time (Berntson et al., 2017). High HRV is one marker of good health, whereas low or absent HRV may indicate poorer health (Gilbert, 2014c). The cardiac waveform, a complex waveform, has several frequency bands (harmonics), the highest of which reflects the rhythmic oscillations of respiratory sinus arrythmia (RSA; Berntson et al., 2017). RSA is the phenomenon of heart rate slowing and speeding in coordination with inhalation and exhalation, respectively, and is influenced by the rate and depth of breath (Berntson et al., 1993). RSA is thought to be an index of vagal control of the heart, which may indicate parasympathetic cardiac control mediated through the cardiac sinuses (Berntson et al., 1993). RSA, measured by indices of HRV, also reflects baroreceptor sensitivity through low frequency bands (0.1 Hz) (Berntson et al., 2017). The baroreceptor reflex coordinates the systems that control heart rate, blood pressure, and vascular tone (Shaffer, 2020). It has been proposed that breathing at certain rates known to maximally influence or reflect baroreceptor systems can amplify cardiovascular oscillations and efficiency (P. M. Lehrer et al., 2020).

In a similar way, the nervous system functions in an oscillatory fashion and is influenced by respiratory oscillations (Schnitzler & Gross, 2005). Mather and Thayer (2018) suggest that increased HRV, which is affected by respiration, may have direct influences on the blood flow within and oscillatory activity throughout the brain, thereby promoting functional connectivity of the brain (Mather & Thayer, 2018). In a study on respiration and neural oscillatory activity in mice, Tort and colleagues (2018) found that nasal respiration was both influenced by and an influence of neural oscillatory activity. In particular, they found that breathing rate caused changes in gamma sub-band oscillations (70-120 Hz), predominantly in the frontal regions of the brain. Additionally, Folschweiller & Sauer (2021) suggest that rhythmic breathing may serve as a timing signal for brain activity. Furthermore, Maric et al. (2020) suggests that the areas in the brainstem that regulate respiration have afferent and efferent connections with the subcortical structures responsible for modulation of emotion and arousal. The nasal route of breathing appears to be of significance to respiration's effects on the oscillatory activity of the brain. In a 2016 controlled cohort study, Schlosser et al. (2016) found that patients with chronic rhinosinusitis (nasal and sinus inflammation) reported higher levels of depression than matched healthy controls. Olfactory bulb impairments, and subsequent symptomatology such as hyposmia (reduced ability to smell), have been related to hippocampal function and subsequently memory, as well as cognitive ability and diseases involving cognitive decline such as Parkinson's Disease and Alzheimer's disease (Biskamp et al., 2017; Bohnen et al., 2010; Nguyen Chi et al., 2016).

Although beyond the scope of this review, it is notable that the rhythmic oscillations of respiration can influence systems of the body beyond the cardiovascular and nervous systems. For example, the rhythmic pressure changes within the thorax exert important functional effects on the gastrointestinal and lymphatic systems (Courtney, 2011; Kolar et al., 2014). Thus, addressing respiratory behaviors can affect general health in domains not typically associated with respiratory behaviors.

Somatic Effects

Somatic effects of breath pattern changes are primarily related to sensory-motor feedback loops within the body. Interoceptive and proprioceptive brain networks receive sensory information from the musculoskeletal respiratory structures (Boyadzhieva & Kayhan, 2021). These networks analyze the sensory information received regarding the state of the body, make predictions about future homeostatic need, and modulate, maintain, or cease motor programs accordingly (Allen et al., 2022). For the purposes of explanation, this process appears linear. In reality, all components are happening continuously and simultaneously. Top-down theories propose that the brain predicts, plans, and deploys physiological responses as needed (Maric et al., 2020). Effectively, the brain commands, and the body responds. Bottom-up theories suggest that interoceptive and proprioceptive sensations are perceived by the brain, thereby predicting and deploying certain behavioral responses, which then perpetuate the perceived state (Barrett, 2018). Still, others suggest that it is a delicate interplay between the both top-down and bottom-up processes (Berry Mendes, 2016).

In terms of breathing, this brain-body coupling is especially complex and essential to optimal body function. The brain deploys certain respiratory patterns in preparation for, or in reaction to, metabolic need, but it also monitors respiratory patterns to inform homeostatic predictions. So, there is a bidirectional relationship in respiratory control creating a sensory-motor feedback loop. When somatic sensory-motor feedback loops are impaired, such as with disease, injury, or in some cases altered by normal aging, the brain is unable to use internal cues to make refined predictions and relies more on external cues to predict homeostatic need (Berry Mendes, 2016). Notably, this process can even occur in the absence of obvious disease or disruption. The sensory-motor feedback loop may be altered by dysfunctional breathing patterns, often referred to as breathing pattern disorders (Chaitow et al., 2014b). For example, imagine a person who is not in danger, but is breathing quickly through the mouth (because they have allergies) with excessive thoracic movement and a tensed abdomen (because they have been sitting down too long). This breath pattern is similar to one seen in states of perceived danger or anticipatory anxiety, despite the person being in a perfectly safe environment (Gilbert, 2014b). In this situation, this person's brain may confuse the interoceptive and proprioceptive signals of their breath pattern as a sign of danger, when in fact they are safe. Subsequently, a deployment of a panic response may further negatively alter the breath pattern.

Clearly, the interactions between the breath pattern and non-respiratory systems of the body are vast and complex. While we have a basic understanding of these interactions, how they play out in real life is less understood. Technological advancements are providing researchers with more accessible, accurate, and in some cases, ambulatory tools which allow for more exploration into respiratory interactions with other body systems.

Measurement of Breath Patterns

Clearly, breath patterns have numerous influences on vital physiological functioning. It is no surprise then that acute or chronic changes in breath pattern, labeled Breathing Pattern Disorders by Chaitow et al. (2014b), can have deleterious effects on overall physical health.

Breath patterns and the effects of breath patterns on other physiologic systems can be quantified using biosensors which measure breathing rate, depth, and route, metabolic efficiency (oxygen saturation and end-tidal CO_2 concentration), heart rate, blood pressure, muscle activation, and skin conductance. Ventilatory movements which reveal breath rate and depth can be assessed using respiratory strain gauge belts, one around the ribcage and one around the abdomen to assess amount of thoracic versus abdominal movement (Gilbert, 2014c). The saturation of oxygen within the blood can be measured using dermal O_2 saturation sensors. Capnometry measures the amount of CO_2 present at the end of each tidal exhalation, indicating whether or not a person is breathing within their metabolic need (McLaughlin, 2014). Surface electromyography (sEMG) allows the monitoring of accessory muscles of respiration, such as the scalenus and trapezius muscles, which, in combination with other measurements, can confirm dysfunctional breathing patterns. Electrocardiography (ECG) monitors and quantifies cardiac activity such as heart rate and derivative measures such as heart rate acceleration, heart rate deceleration, and heart rate variability. A sphygmomanometer, or blood pressure cuff, monitors blood pressure changes as a result of respiratory and autonomic fluctuations (Lorig, 2016).

Respiration and Speech-Language Pathology Scope of Practice

Despite respiration falling within the scope of practice in speech-language pathology, especially rehabilitation of ventilation patterns, its focus has frequently been on its supporting role in voice, speech, swallowing, and cough and less on a behavior in-and-of-itself (American Speech-Language-Hearing Association, 2016).

The most obvious area in which speech-language pathologists (SLPs) would address breathing would be when working with people with upper airway or voice disorders, as respiration is a fundamental component of both (Vertigan et al., 2019). Recent investigations of breath pattern as it relates to conditions such as Exercise Induced Laryngeal Obstruction and Post-COVID voice and upper airway disorders provide further support for SLP breath-based intervention in these realms (Golan et al., 2023; Milstein et al., 2023).

Given the fundamental nature of respiration to speech production, voice and upper airway disorders are not the only speech-language realms in which breath pattern plays an integral role. Jones et al. (2017) investigated the relationship between changes in RSA and episodes of disfluency in children who do and do not stutter. They found that a decrease in RSA was correlated with an increase in disfluencies in both children who stutter and children who do not stutter (Jones et al., 2017). Thus, breathing training that focuses on affecting RSA might be appropriate in fluency treatment. Additionally, many neurological conditions which result in motor speech disorders, may also impact respiration (Mehanna & Jankovic, 2010). It is therefore not unlikely that a patient with a motor speech disorder may also present with inefficient ventilation which exist in isolation of or contribute to their speech issues. For example, in hypokinetic diseases such as Parkinson's Disease, reduced ventilatory movement and subsequently loss of air pressure for voice and speech is of primary concern for voice, speech, and swallowing (Yorkston et al., 2010, pp. 463–466).

In addition to speech-related breathing retraining, investigations into dysphagic populations with Chronic Obstructive Pulmonary Disease (COPD) have revealed a relationship between ventilatory mechanics and swallowing (Drulia et al., 2021). Expiratory Muscle Strength Training (EMST) has been proposed as a treatment strategy to improve ventilatory strength and subsequently swallowing in populations with COPD (C. M. Sapienza, 2008). A recent meta-analysis and systematic review concluded that while higher-level research was needed to validate the use of EMST for dysphagia in people with COPD, initial results were promising (Patchett et al., 2017).

The lion's share of research about breathing and the implementation of breathing retraining within speech-language pathology treatment clearly focuses on the mechanics of breathing and breathing behavior (see for example, C. Sapienza & Hoffman, 2021) and not necessarily the effects of using breathing therapeutically to enact change upon less obvious systems, such as mood and affect, or cognition and executive function. Beyond the obvious effects of training coordinated breath patterns and strengthening respiratory structures, recent literature suggests breath pattern manipulation may be an effective tool for improving mood, emotional regulation, and executive functioning abilities, all of which are important for any discipline related to rehabilitative care (Hsu et al., 2020; Laborde, Allen, Borges, Hosang, et al., 2022; Leganes-Fonteneau et al., 2021; P. Lehrer et al., 2013; Maric et al., 2020; Mather & Thayer, 2018; Petta, 2017; Price et al., 2022; Steffen et al., 2017; Thayer et al., 2009).

Breath Patterns and Psychology

The influence of psychological states on respiration is exerted primarily through the activation, or co-activation, of the sympathetic and parasympathetic branches of the autonomic nervous system (ANS). However, this relationship is anything but straightforward. Not only do the conditional stimuli that trigger ANS activation vary from person to person and moment to moment, but the type and extent of activation may vary from organ system to organ system

(Hayano & Yuda, 2019). It is possible, then, to have sympathetic dominance in one part of the body and parasympathetic dominance in another. This is a primary argument against the use of HRV and derivative measures to determine autonomic state (Hayano & Yuda, 2019). Additionally, as we have discussed, respiration is not always under autonomic control, so the extent to which the ANS influences respiration may vary depending on the level of conscious control of respiration.

Despite lack of certainty surrounding the activation of both branches of the ANS, efforts have been made to attribute specific autonomic physiological responses to psychological states (Berntson et al., 2016). Many researchers over the past century have attempted to map discrete emotions onto specific physiologic patterns (Boiten, 1998; Faulkner, 1941; Feleky, 1916; Rehwoldt, 1911; Skaggs, 1926). However, this assumes, that discrete emotional states exist at all. There is much debate about not only if discrete emotions exist, but if they are universal as opposed to culture-specific, and if they are innately ingrained or constructed by predictions and experience (Barrett, 2018; Levenson et al., 2016). In light of this uncertainty, other researchers have sought to explain physiologic signatures by other dimensions such as valence-arousal, and motivational systems such as approach-avoidance and threat-challenge (Davidson et al., 2000; Levenson et al., 2016). Vlemincx and colleagues (2015) suggest a predator-prey imminence model that not only includes the neurobiological motivational system of threat-challenge, but also the environmental imminence of the threat or challenge. They found that negatively valanced emotions, high-arousal emotions, or both, led to increased respiratory variability measured by variability in end-tidal CO_2 and expiratory time. Conversely, depressive emotions, which are negatively valenced, low arousal emotions, resulted in a decrease in respiratory variability. A review by Boiten and colleagues found that emotional arousal, as opposed to valence, had the greatest effect on respiratory dimensions (Boiten et al., 1994). Furthermore, some suspect that physiological responses to emotional stimulation may be more reliant on the interactions between arousal and attentional processes (Schimmack & Derryberry, 2005). In a study on emotional physiology and personality, Brumbaugh and colleagues (2013) found greater increases in arousal following picture stimuli that increased use of controlled attention. Thus, cognitive functions, such as attentional processes, may influence emotional arousal and respiratory pattern. Conversely, breathing patterns that alter cognitive function may influence emotional reactivity, specifically arousal.

While emotional experiences' impact on respiration have been a subject of interest for quite some time, interest in the effects of cognition on respiration are more recent. Cognition refers to all of the mental processes through which we acquire understanding or knowledge (Britannica, 2021). Cognition is controlled and coordinated by executive function processes (Miyake et al., 2000). Categorization and labeling of executive function skills vary, but in general, they include the ability to update and monitor information (working memory), shift attentional resources as necessary, and inhibit unnecessary responses (Blair, 2017; Miyake et al., 2000). Mental load (also known as cognitive load or mental workload) refers to the amount of cognitive resources required to complete a task (Young et al., 2014). In a systematic review of 53 articles, Grassmann et al. (2016) explored the effects of mental load on respiratory parameters. They found that respiratory rate and minute volume increased with increased mental load. They surmised this was due to both an increase in immediate and predicted metabolic need. Furthermore, they suggest that additional respiratory parameters such as sigh frequency, partial pressure of end-tidal CO_2, and oxygen consumption may also be affected by cognitive load, but due to lack of quantity and quality of studies found, they could not draw any firm conclusions.

Clearly, cognition and emotion play a part in modulating respiratory behavior. However, this relationship is not unidirectional. Breath pattern has the ability to influence cognition and emotion in return. This idea of breath-over-mind influence is not new. In fact, longstanding traditions such as yoga, prayer, chanting, and singing suggest that humans have instinctively reaped the psychological benefits of breath modulation throughout most of human existence. While theories regarding the mechanisms through which psychology impacts respiration remain to be refined, sound theories and supporting evidence regarding the impact of respiration on psychology are emerging and supporting these ancient practices.

Resonance Frequency Breathing

Recently, researchers have begun to propose theories which would explain the effects of slow, rhythmic breathing (such as during meditation or prayer) on emotion and cognition. Mather & Thayer (2018) lay out mechanisms through which respiration, and subsequently the cardiovascular system, may affect emotion regulation brain networks. They suggest that when respiration oscillations entrain with cardiovascular rhythms, they increase HRV and the amplitude of the cardiovascular oscillations. These effects of slow breathing patterns are most often achieved when breathing at a frequency of 0.1 Hz, often called resonance frequency breathing or coherence breathing. This cardiorespiratory entrainment provides increased blood flow to distal regions of the brain, especially the prefrontal cortex and limbic regions, which promotes the functional connectivity of the brain regions, and thus support executive functions and emotional processing. Zelano et al. (2016) found that nasal breathing phase (nasal inhalation versus nasal exhalation) affected memory recall and emotional judgements. Their participants were better able to remember emotional faces and objects when stimuli were presented during a nasal inhalation. Boyadzhieva and Kayhan (2021) suggest this may be due to the coupling of olfactory cortex oscillations with amygdala and hippocampal activity. Animal models have further suggested a relationship between respiratory-hippocampal oscillatory entrainment (Liu et al., 2017; Yanovsky et al., 2014). As previously mentioned, emerging research supports the theory that respiratory oscillations are a fundamental rhythm over which neural oscillations entrain, thus respiration drives this entrainment and links respiration to neural activity, including cognitive and emotional processes (Heck et al., 2017; Herrero et al., 2018; Maric et al., 2020; Tort, Ponsel, et al., 2018; Varga & Heck, 2017; Zelano et al., 2016).

Breath Manipulation in Modern Society

Explicit breathwork in modern society is rare. Nonetheless, the field of psychotherapy has been interested in breathwork for quite some time. Czech physician, Dr. Stanislov Grof is a prominent figure connecting breathwork and psychotherapy. His technique called *holotropic breathwork* was meant to induce a holotropic state, using hyperventilation and sensory stimulation to "release residual bioenergetic and emotional blocks." (Grof & Grof, 2010, p. 1) This work was further explored by Dr. Todd Pressman in his 1993 doctoral thesis. He explored the effects of holotropic breathwork on psychological and spiritual experiences through a pre-test/post-test control group design. He found that the treatment group (those undergoing holotropic breathwork sessions) demonstrated positive results for the psychological and spiritual effects as measured quantitatively by The Profile of Mood States Questionnaire, the Brief Symptom Inventory, and the Spiritual Orientation Inventory and qualitatively by a structured interview analysis (Pressman, 1993). Despite acknowledgement of the importance of breath in psychology dating back to the Greeks, modern mainstream psychology places less of an emphasis on breath manipulation. Some even treat it as a separate treatment technique, not a tool for integration, referring to psychological treatment involving breathwork as "breath psychology" (Edwards, 2008).

While explicit breath manipulation practices are relatively uncommon in Western culture, many health practices involve focused attention to breath and breath manipulation. An obvious example of this would be yoga. Yoga has boomed in popularity in the United States over the past thirty years. According to the 2016 Yoga in America study, the amount of people practicing yoga grew 50% from 20.4 million in 2012 to 36.7 million in 2016 (Ipsos Public Affairs, 2016). In 2012, over 85% of adults doing yoga reported doing so to reduce stress (Stussman et al., 2015). Yoga's increase in popularity is not limited to committed yoga practitioners. Yoga and its health benefits have become a primary research interest of various groups such as the National Center for Complimentary and Integrative Health (NCCIH, 2021). Furthermore, over recent years there has been a shift in education towards the inclusion of yoga, meditation, and mindfulness activities in the classroom to help children regulate emotions and relieve stress. A 2018 meta-analysis of 24 studies on mindfulness intervention programs in schools (many of which use yoga) found small to moderate significant effects of mindfulness intervention on mental health and overall well-being in the mindfulness groups as compared to the control groups (Carsley et al., 2018).

Despite the fact that the history of breath manipulation practices spans thousands of years and myriads of cultures and religions, its benefits remain largely unexplored with recent technological and scientific advances and largely underappreciated by modern medical practice. However, the small amount of research that does exist appears to validate why breath manipulation practices have persevered for so long throughout diverse cultures and religions. Our hope is that scientific validation of the interactions between breath and other body systems will influence modern society to place more importance on the impacts of breath pattern on health and wellbeing.

Purpose

The purpose of this study is to investigate the effects of breathing on emotional regulation and inhibition. It is widely accepted that respiration is one of the only physiologic rhythms that is under both volitional and autonomic control. Additionally, it is understood that respiratory parameters (i.e., rate, ratio, depth, impedance, route, etc.) interact with and influence other physiologic rhythms, including cardiovascular rhythms (e.g., heart rate and blood pressure) and neural oscillations. What is less understood is the degree to which respiratory changes (automatic or volitional) impact cognition and emotion.

Utilizing self-report, behavioral, and physiological measurements, this study examined the impacts of three different breath patterns (controlled neutral, resonance frequency, and variable breathing) on emotional reactivity and inhibition.

We hypothesize that resonance frequency breathing (breathing at a frequency that resonates with the cardiovascular system) will increase inhibitory abilities and decrease emotional reactivity as compared to baseline, controlled neutral, and variable breathing.

Specifically, in self-report measures of valence (The Self-Assessment Manikin for Valence), we hypothesize that participants will demonstrate no difference in valence by breath condition, but we hypothesize that in self-report measures for arousal (The Self-Assessment Manikin for Arousal) participants will indicate lower levels of arousal following resonance frequency breathing in keeping with past literature suggesting that breathing influences emotional experiences by moderating arousal levels (Boiten et al., 1994; Schimmack & Derryberry, 2005). We also hypothesize higher levels of arousal following variable breathing as compared to unaltered and controlled neutral breathing. We hypothesize that participants will report higher levels of negative affect on the Positive and Negative Affect Schedule following variable breathing as compared to the other breathing conditions.

In physiological measures of behavior, we hypothesize that following resonance frequency breathing, participants will experience decreased levels of tonic muscle activity in the corrugator and zygomaticus muscles as measured by surface electromyography, given that this breathing pattern has demonstrated a moderating effect on emotional processing (Heck et al., 2017; Maric et al., 2020; Tort, Ponsel, et al., 2018; Varga & Heck, 2017; Zelano et al., 2016). We hypothesize that following variable breathing, participants will demonstrate increased levels of tonic muscle activity in the corrugator and zygomaticus muscles.

In behavioral measures of inhibition, we hypothesize that resonance frequency breathing will result in a decrease in response time to non-stop signal trials and an increase in response accuracy to stop-signal trials in the Stop Signal Task, indicating an increase in inhibitory modulation and control. An increase in inhibitory control would affect not only increase the speed of non-stop signal responses but increase the accuracy of stop-signal responses, resulting in an overall increase in inhibitory function. Conversely, we hypothesize that variable breathing will result in an increase in non-stop signal trial response time and a decrease in stop-signal trial response accuracy in the Stop Signal Task, indicating a decrease in inhibitory control.

Such results would have a myriad of clinical implications for a wide variety of disciplines and disorders. Our hope is that breathwork will become a more mainstream practice in speech and language pathology as a way to promote efficacy of rehabilitative treatments for all of the various disorders which fall under our scope of practice.

Methods

Participants

Given the past literature comparing individuals using psychophysiological measures, a sample of 40 individuals would provide robust effects in physiological measures. However, given the large number of participant trials in this paradigm, smaller sample sizes may still provide robust findings in self-report measures of emotional reaction and reaction times during inhibitory tasks. Utilizing a within-participant paradigm, each individual served as their own control and was exposed to all conditions and stimuli.

Participants were healthy adults between the ages of 18-65. Participants had adequate English language and visual abilities to understand directions and follow prompts. This was identified prior to the experimental procedures by way of asking directly on an intake form. Participants had no active cough. See Table 1 for participant information.

Table 1
Participant Information

Demographic information		*n*	*Percent*
Gender	*Male*	10	38.50
	Female	16	61.50
Race	*White*	21	80.78
	Black, African American	4	15.38
	Asian Indian	1	3.85
*Breathing Status**	*Breathers*	13	50
	Non-Breathers	13	50
*Resonance Frequency Breathing Rate (seconds)***	*4.5*	2	7.69
	5	3	11.54
	5.5	6	23.08
	6	5	19.23
	6.5	7	26.92
	7	3	11.54

	Range	*Mean*	*Standard Deviation*
Age (years)	21.43-52.90	31.66	7.16
Height (inches)	61-74	67.08	3.73
Rib Cage Diameter (centimeters)	64-125	85.42	12.63

**Breathers were participants who reported active involvement in activities that require advanced respiratory control, such as singing or yoga. Non-breathers were participants who reported not participating in any activity requiring advanced respiratory control.*
***Resonance Frequency Breathing rate in seconds refers to the number of seconds per inhale and exhale. Breath cycle rate (inhale and exhale) may be calculated by multiplying the listed rate by two.*

Measures

Independent measures

In our study there are three categories of independent measures: breath pattern manipulation tasks, a cognitive task, and emotional stimuli.

Breath Pattern Manipulation Conditions.

Prior to the experiment, participants were instructed on the target breath pattern. During the experiment, participants were led through the breath by audio-visual prompts. See Figure 1 for the breathing symbol key. Audio prompts included musical cues designed to mimic the breath task (e.g., an ascending arpeggio for an inhale, a descending arpeggio for an exhale, two staccato chords for the paired sniffs, etc.). The audio cues were presented using a neutral piano sound. Participants completed each breath for five minutes prior to the Stop Signal Task and for three minutes prior to the picture stimuli. Participants were monitored visually by the researcher and by physiologic sensors to ensure adherence to the target breath pattern.

Breathing manipulation tasks consisted of three different patterns of breathing: controlled neutral, variable, and resonance frequency. The controlled neutral breathing served to facilitate comparisons across participants. Following the unaltered baseline of sitting quietly, the three breath pattern manipulation conditions were randomly ordered utilizing a random number generator.

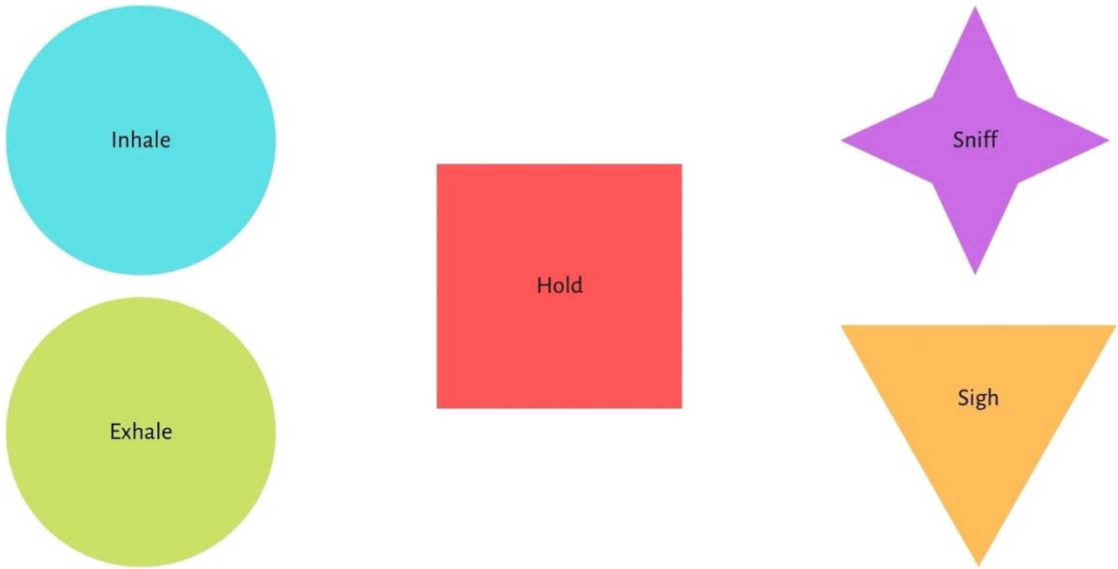

Figure 1 *Breathing Symbol Key*

Controlled Neutral Breathing. The controlled neutral breathing task reflected a typical breathing style but with focused attention on not changing anything drastic to the pattern. Participants were informed that they were to breathe at a comfortable depth and follow along with the audio-visual prompts which alternated between the "inhale" and "exhale" symbols at 16 breaths per minute with an inhalation-exhalation ratio of 1:1.5 (1.5 second inhales and 2.25 second exhales). Participants were instructed to breathe through the nose.

Resonance Frequency Breathing**.** Resonance frequency breathing is breathing in a slow, relaxed way that resonates with the cardiovascular and nervous systems. It is similar to the kind of breathing people do when they meditate. Each individual's resonance frequency breath rate was determined at the beginning of the experiment. Participants were instructed to follow the audio-visual cues for rate (as determined per participant) and ratio (1:1 inhalation to exhalation ratio). Participants were instructed to breathe through the nose.

Variable Breathing. The variable breath task consisted of random patterns of hyperventilation, apnea, sniffs, and sighs. For variable breathing, participants were instructed to follow the visual prompts closely because the depth, rate, and ratio of breathing patterns were varied and unpredictable throughout the breathing task.

Emotional Stimuli.

International Affective Picture Stimuli (IAPS). Following each experimental condition, participants underwent emotional induction using the IAPS and physiologic responses to the stimuli will be recorded. The IAPS are a system of emotional picture stimuli that are designed to elicit particular emotions of varying arousal, valence, and dominance in the viewers (Lang et al., 2008). IAPs pictures are normed and validated and have been used in numerous experimental studies. Pictures were chosen for positive, negative, and neutral valence. Arousal was commensurate between the positive and negative images. Eight images per emotion condition, positive, negative, and neutral were presented for six seconds each via a computer screen. We hypothesized that following resonance frequency breathing, participants would demonstrate less of an increase in arousal as compared to unaltered or controlled neutral breathing. We hypothesized that following variable breathing, participants would demonstrate the greatest increase in arousal as compared to all breathing conditions. Given the manipulation in arousal, we further hypothesized that in the resonance frequency breathing condition, participants would have a modulating effect on mood, where both positive and negative pictures would be rated as less positive or negative, respectively.

Cognitive Tasks.

Stop-Signal Task. After each experimental condition participants underwent a cognitive task, the Stop Signal task, which measures inhibitory abilities (Lappin & Eriksen, 1966). The Stop Signal task is a reaction time task where a participant is asked to respond as quickly as possible to a stimulus (saying the sound /du/) unless a stop sign is presented at that signal. They are instructed to immediately stop the task if the stop signal appears. However, the immediacy of the stop signal varies between trial (100 ms, 200 ms, 300 ms), with longer latencies increasing difficulty of response inhibition. Behavioral measures of reaction time and reaction accuracy to the stop signal were collected and provided information regarding inhibitory abilities. We hypothesized that resonance frequency breathing would increase inhibitory abilities as compared to the baseline and controlled neutral breathing. We hypothesized that variable breathing would decrease inhibitory abilities. Inhibitory abilities were measured by reaction time on non-stop signal trials and reaction accuracy following the stop signals. The task was presented on a computer screen.

Dependent Measures

Dependent measures tracked changes across conditions via self-report, physiological, and behavioral responses to presented stimuli.

Self-Report Measures.

The Self-Assessment Manikin for Valence (SAM-V). The SAM-V is a nine-point scale which measures levels of valence from pleasant (9) to not pleasant (1) and utilizes five pictures to illustrate the degrees of valence (M. M. Bradley & Lang, 2000). The SAM-V was presented immediately after picture viewing via computer and the participants indicated how pleasant or unpleasant they felt while viewing the picture. We hypothesized that variable breathing would induce higher incidence of unpleasant valence as compared to the baseline, controlled neutral, or resonance frequency breath patterns.

The Self-Assessment Manikin for Arousal (SAM-A). The SAM-A is a nine-point scale which measures levels of arousal from calm (9) to excited (1) and utilizes five pictures to illustrate the degrees of arousal (M. M. Bradley & Lang, 2000). The SAM -A was presented immediately after picture viewing via computer and the participants indicated how aroused they felt while viewing the picture. This self-report measure provided data to compare to the physiological arousal measurements taken during picture viewing. We hypothesized that variable breathing would induce higher levels of arousal as compared to the baseline, controlled neutral, or resonance frequency breath patterns.

Positive and Negative Affect Schedule (PANAS). The PANAS is a 20-item self-rating scale designed to measure positive and negative affect (Carver & White, 1994). This measure was taken immediately after each breath condition to record positive or negative emotional state. Participants completed the PANAS via computer. We hypothesized that participants would indicate higher levels of negative affect following variable breathing.

Physiologic Measures.

Surface Electromyography (sEMG). Tonic levels of activation of the corrugator and zygomaticus muscles were measured to assess emotional responses (M. M. Bradley & Lang, 2000). These measures served as indicators of emotional experience.

Behavioral Measures.

Behavioral measures of interest include response time and accuracy in the Stop Signal task (Lappin & Eriksen, 1966). Both response time for non-stop signal trials and accuracy for stop signal trials were extracted from the E-Prime 3.0 program. These measures tracked whether inhibitory control changed across conditions. An increase in response time (slower) accompanied by a decrease in accuracy indicate a decrease in inhibition.

Control measures to ensure inclusion criteria and provide post hoc analysis.

Informal Intake and Questionnaire. Self-report measures consisted of an informal intake and questionnaires. Participants completed an informal intake surveying demographics, medications that may affect physiologic variables of interest, prior surgical history and/or thoracic, abdominal, or pelvic trauma, respiratory diseases or disorders, disorders affecting the autonomic nervous system (e.g., post-acute COVID-19, POTS, etc.), major neurological or psychological conditions, and advanced training in respiration-related activities (e.g., singing, yoga, free-diving, etc.). This was given prior to experimental tasks via a tablet. All inclusion and exclusion criteria were assessed through this informal intake process through self-report.

Self-Evaluation of Breathing Questionnaire (SEBQ). Following informal intake, participants completed the SEBQ (Courtney & Greenwood, 2009). The SEBQ is a 25-item self-report measure is designed to assess the presence of respiratory symptoms and breathing behaviors which are associated with breathing dysfunction. The SEBQ differentiates between objective (e.g., pain) and subjective (e.g., psychological breathing complaints) symptoms of breath dysfunction to better illuminate the root cause of breathing dysfunction. This measure served as a control variable to verify that all participants' individual differences did not influence the pattern of data.

Emotion Regulation Questionnaire (ERQ). The ERQ was given to participants prior to the experimental portion of the study (Gross & John, 2003). The ERQ is a 10-item questionnaire designed to assesses participant's tendencies to regulate emotions. It evaluates both of the emotional regulation strategies of cognitive reappraisal and emotional suppression tendencies via a seven-point Likert scale, one being strongly disagree and seven being strongly agree. Participants completed the ERQ via computer. This measure served as a control variable to verify that all participants' individual differences did not influence the pattern of data.

Generalized Anxiety Disorder-7 (GAD-7). The GAD-7 is a 7-item questionnaire designed to screen for symptoms of Generalized Anxiety Disorder (Spitzer et al., 2006). Each item lists a symptom and participants rate the symptom based on how often they experience it from zero ("not at all") up to three ("nearly every day"). Each column total is combined for a total score ranging from 0-21. A score of 0-4 represents minimal anxiety, 5-9 mild anxiety, 10-14 moderate anxiety, and 15-21 severe anxiety. The GAD-7 was used to assess participants for symptoms of anxiety and was administered via computer prior to the experimental tasks. This measure served as a control variable to verify that all participants' individual differences did not influence the pattern of data.

Procedures

Upon arrival, participants completed an informed consent form and were introduced the protocol for the experiment. The experimenter placed a small amount of electrode paste on the participant's wrist to test for allergic or sensitive reactions. Participants completed the intake questionnaire and the PANAS questionnaire. When five minutes had passed, the experimenter checked the participant's wrist for any reaction to the electrode paste. If positive for an allergic or sensitive reaction, they were excused from the study.

Participants were informed regarding the macrostructure of the experiment (e.g., breathing, presentation of stimuli, questionnaire, repeat). They were not informed on specific breath patterns or the order in which the breaths will be presented. Following macrostructure instruction, they were informed regarding the physiological measurements being taken, the type of stimuli being presented (pictures), the process of determining their individualized rate for resonance frequency breathing (although, they were not informed about what the process was determining), and finally, the questionnaires they would be answering. The researcher measured and noted the participant's height and ribcage circumference (measured at the level of the xiphoid process).

Participants were fitted with physiologic sensors and the sensors were calibrated according to convention. Once all sensors were fitted and calibrated, the participants received instruction on how to follow the visual and audio cues throughout the breathing segments. Participants were told to breathe through the nose as much as possible, only resorting to pursed lip breathing briefly when absolutely necessary. Following this instruction period, five minutes of baseline HRV data was collected while the participant sat quietly.

Following five minutes of baseline HRV data collection, participants underwent a resonance frequency breathing rate determination to determine their individual breathing rate. Resonance frequency breathing is breathing at a neutral depth with a 1:1 inhalation-exhalation ratio at a rate that resonates with the individual's cardiovascular system. Individual's resonance frequency breathing rate typically fall between 4.5-7.5 breaths per minute. Participants completed a 15-minute process of determining their resonance frequency breath rate utilizing a protocol based on Fisher & Lehrer's stepped protocol, in which participants will breathe at progressively slower rates for a predetermined amount of time (Fisher & Lehrer, 2022). The participants were instructed to breathe along with a video which guided them through approximately 2.5 minutes of six breathing frequencies: 9, 10, 11, 12, 13, and 14 second breath cycles (inhalation and exhalation). For the five minutes prior and during the fifteen minutes of the determination process, researchers recorded the ECG data. At the conclusion of the video, the researchers converted the raw ECG data to an EDF file and analyzed the data in Kubios HRV Premium.

In Kubios HRV Premium, data was segmented into two-minute windows corresponding to each breathing rate. The final two minutes for each rate was analyzed to protect against effects from the preceding rate. The window was correlated to the determination video, and the rate was selected by analyzing factors outlined in Shaffer & Meehan (Shaffer & Meehan, 2020). These factors were reformatted into a table which was filled out for each participant during HRV analysis (see Figure 1). These measures, in order of importance, include phase synchrony between heart rate and respiration rate, peak-to-trough amplitude (HR maximum-HR minimum), number of low frequency (LF) peaks, LF power (in percentage), and magnitude of the maximum LF amplitude peak, and regularity of the heart rate curve envelope. Desirable features include maximum peak-to-trough amplitude, least number of LF peaks, maximum percentage of LF power, and greatest magnitude of LF amplitude peak (See Figures 2 and 3), and a sinusoidal heart rate curve envelope. The rate which was found to have the most desirable factors was chosen. If a participant fell between two rates, the faster rate was chosen for participant comfort.

RFB Determination Table

RFB Rate/Video Time Window	4.5/ 0:00-2:24	5/ 2:24-4:54	5.5/ 4:55-7:28	6/ 7:29-10:16	6.5/ 10:17-12:39	7/ 12:40-15:00	End (15:00)
Exact Time CST (H:M:S)							
Phase Synchrony: HR and RR (º)							
HR Max							
HR Min							
Peak-to-Trough Amplitude (HR Max- HR Min) (bpm)							
Number of LF Peaks							
LF Power (%)							
Estimated Maximum LF Amplitude Peak (PSD (s^2/Hz)							
HR Curve Envelope (smooth/sinusoidal/regular (R) OR irregular (IR))							

Figure 2 *Table Based on Shaffer & Meehan, 2020 Resonance Frequency Determination Criteria*

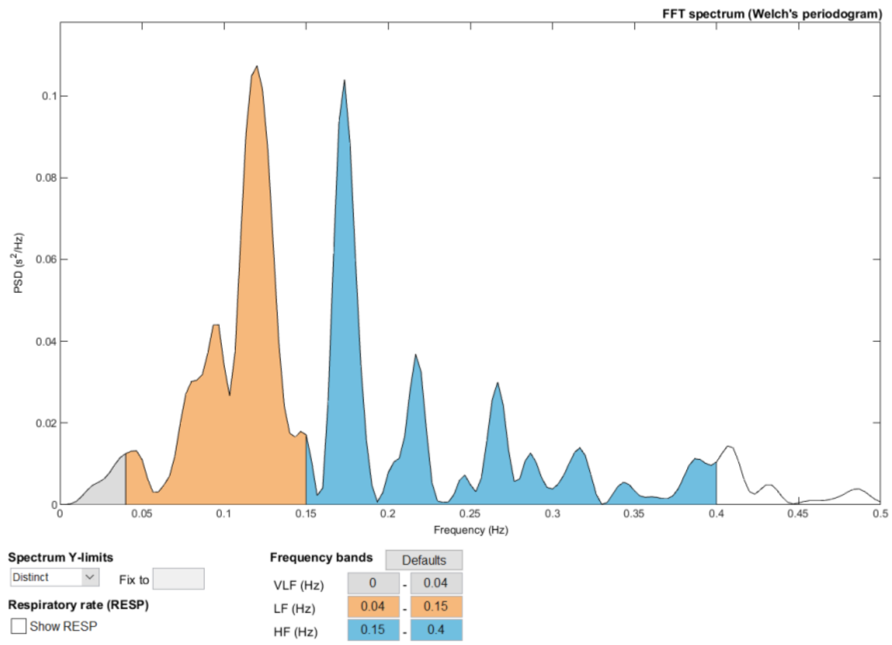

Figure 3 *Screenshot of Kubios HRV Premium Fast Fourier Transform of Heart Rate Variability During Tidal Breathing*

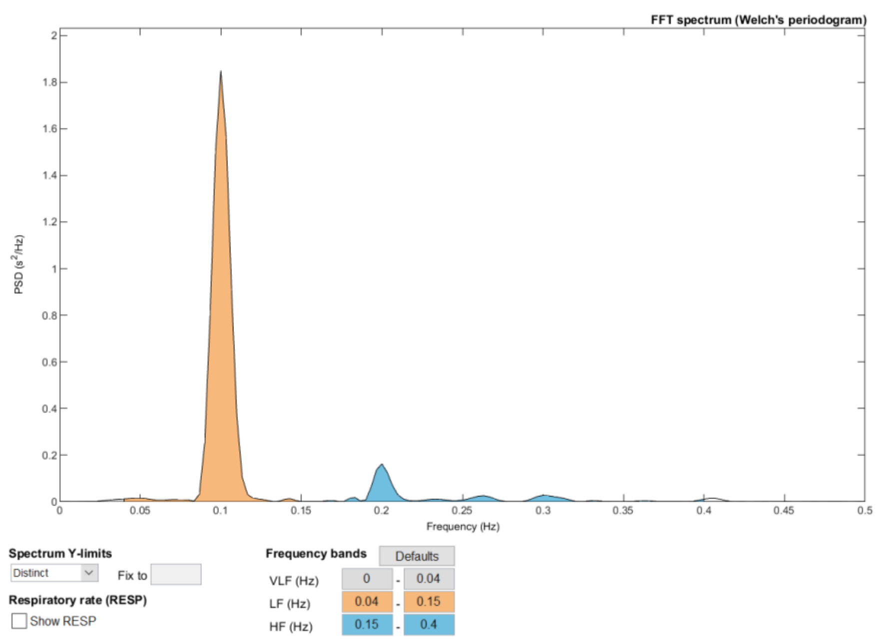

Figure 4 *Screenshot of Kubios HRV Premium Fast Fourier Transform of Heart Rate Variability During Resonance Frequency Breathing*

Following the determination procedure, participants completed the SEBQ, GAD-7, and ERQ. Next, they were shown a reference key of symbols utilized in the breathing videos and led through practicing each breath type (e.g., inhale, exhale, hold, sniff, sigh). They were asked to ensure the sigh was silent. Finally, they received instructions on the Stop Signal task and IAPS task and completed a shortened practice round of each task. This training period provided time for the effects of the resonance frequency breathing to wash out. Once completed, the experiment began.

The first block established the participant's baseline measures. Participants completed the PANAS. Next, they participated in a full-length Stop-Signal task. Then they were presented with IAPS picture stimuli. After each round of picture stimuli, participants completed the SAM-A and SAM-V.

For the remaining three blocks, breath condition order was randomly assigned for each participant using a random number generator. To begin each block, participants employed the target breath for five minutes. To ensure the participants were adhering to the experimental breath parameters, they were instructed to breathe in sync with audio and visual cues, which reflected the parameters of the chosen breath (controlled neutral, variable, or resonance frequency). They were also monitored by the experimenters via the physiological sensors. Following five minutes of breathing, they completed the PANAS. They were then presented with the Stop Signal Task. Following this, they employed the target breath pattern for an additional three minutes. Next, they completed the IAPs picture stimuli, followed by the SAM-A and SAM-V.

Five minutes of neutral video viewing concluded the second and third blocks to wash out the effects of the previous experimental condition. After the fourth block, participants were disconnected from the sensors and asked informal follow-up questions about the experiment.

The entire experiment lasted approximately two hours.

Instrumentation and Experimental Set Up

Visual Stimuli was presented using E-Prime (3.0 Psychology Software Tools, Pittsburgh) running on a Dell OptiPlex 7050 MT, (Austin, TX) and displayed on a 60-Hz, 1,080-p, 48" high-definition monitor (LG LED LK5700, Seoul, South Korea). Data was collected using Brain Recorder (BrainVision; Morrisville, NC) which collects on a Dell OptiPlex 7050 MT.

Electromyographic measures were segmented according to breath condition and block and processed via BrainAnalyzer software (Morrisville, NC).

Analysis

Self-Report Measures

Self-report data of mood and arousal from the SAM-A and SAM-V following each picture viewing were averaged within each block for pleasant, neutral, and unpleasant pictures. A two-way ANOVA comparing slide arousal (aversive, neutral, positive) by condition (controlled neural, variable, and resonance frequency breathing) determined any significant differences in transient mood across the breathing conditions. A two-way ANOVA comparing slide valence (aversive, neutral, positive) by condition (baseline, controlled neural, variable, and resonance frequency breathing) determined any significant differences in arousal across the breathing conditions. A one-way ANOVA of the self-report data of overall mood from the PANAS across conditions (baseline, controlled neural, variable, and resonance frequency breathing) determined any significant differences in general mood.

Physiological Measures

Influences breathing on emotional expression from the corrugator supercilii and zygomaticus major muscle following each picture viewing were averaged within each block for pleasant, neutral, and unpleasant pictures. A two-way ANOVA comparing slide valence (aversive, neutral, positive) by condition (baseline, controlled neural, variable, and resonance frequency breathing) determined any significant differences in emotional expression in the corrugator supercilia, particularly in positive conditions across the breathing conditions. A two-way ANOVA comparing slide valence (aversive, neutral, positive) by condition (baseline, controlled neural, variable, and resonance frequency breathing) determined any significant differences in emotional expression in the zygomaticus major, particularly in positive conditions across the breathing conditions.

Behavioral Measures

Two, one-way ANOVAs determined the behavioral influences of breathing on inhibitory control. The first one-way ANOVA assessed if response time in the Stop Signal tasks were influenced by the breathing conditions: baseline, controlled neural, variable, and resonance frequency breathing. The second one-way ANOVA assessed if accuracy in the Stop Signal tasks was influenced by the breathing conditions.

Results

Emotional Reactivity

Self-Report Measures

SAM-V. Participants demonstrated expected self-report emotional responses to slide valence. However, there was no conclusive pattern for breathing condition. See Figure 4. A two-way ANOVA was performed to evaluate the effects of slide valence and breathing condition valence on self-reported valence of the SAM-V. The means and standard deviations for SAM-V ratings are presented in Table 2 below.

Results indicated a significant main effect for slide valence, $F(2, 2484) = 1946.845$, $p = < .001$, partial $\eta 2 = .611$; no significant main effect for the breathing condition, $F(3, 2484) = .286$, $p = .835$, partial $\eta 2 = .000$; and no significant interaction between valence and breathing condition, $F(6, 2496) = .469$, $p = .832$, partial $\eta 2 = .001$.

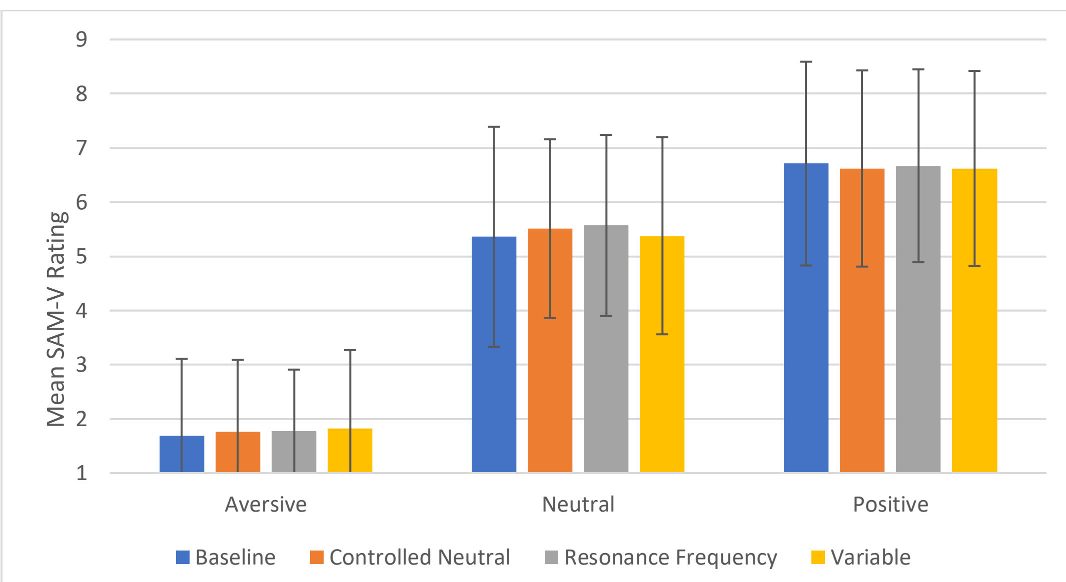

Figure 5 *Mean SAM-V Rating for Positive, Neutral, and Aversive Stimuli by Breath Condition*

Table 2
Descriptive Statistics for SAM-V Responses

Breathing Condition	*Slide Valence*	*M*	*SD*
Baseline	*Aversive*	1.69	1.42
	Neutral	5.36	2.03
	Positive	6.71	1.88
Controlled Neutral	*Aversive*	1.76	1.33
	Neutral	5.51	1.65
	Positive	6.62	1.81
Resonance Frequency	*Aversive*	1.77	1.14
	Neutral	5.57	1.67
	Positive	6.67	1.78
Variable	*Aversive*	1.82	1.45
	Neutral	5.38	1.82
	Positive	6.62	1.80

SAM-A. Participants demonstrated expected self-report arousal responses to slide arousal. However, there was no conclusive pattern for breathing condition. See Figure 5. A two-way ANOVA was performed to evaluate the effects of slide arousal and breathing condition arousal on self-reported arousal of the SAM-A. The means and standard deviations for SAM-A ratings are presented in Table 3 below.

The results indicated a significant main effect for slide arousal, F (2, 2484) = 456.08, p = < .001, partial η2 = .269; no significant main effect for the breathing condition, F(3, 2484) = 1.447, p = .227, partial η2 = .002; and no significant interaction between arousal and breathing condition, F(6, 2496) =.315 , p = .930, partial η2 = .001.

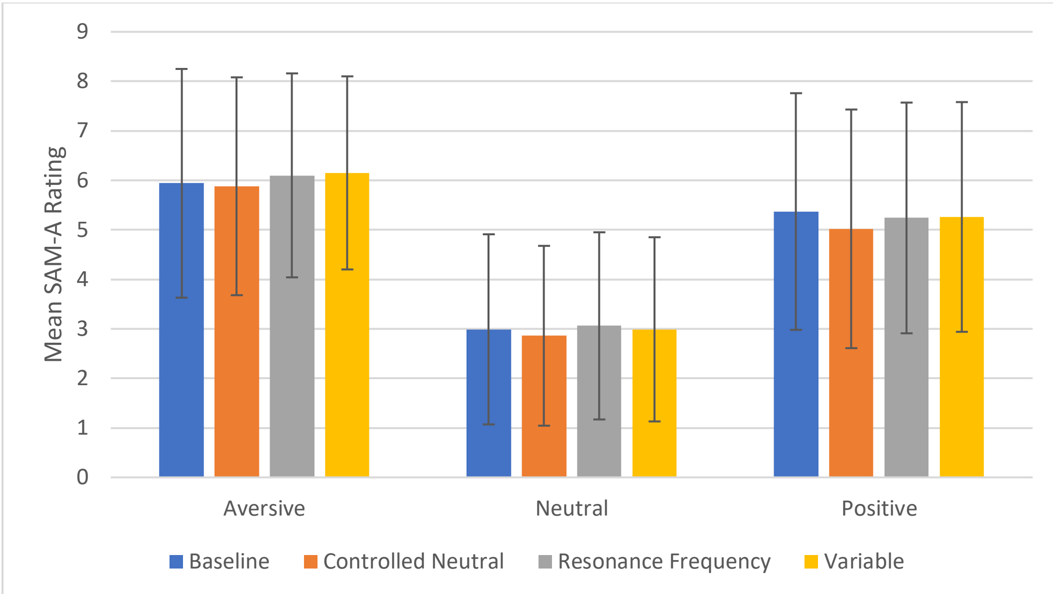

Figure 6 *Mean SAM-A Rating for Positive, Neutral, and Aversive Stimuli by Breath Condition*

Table 3
Descriptive Statistics for SAM-A Responses

Breathing Condition	*Slide Valence*	*M*	*SD*
Baseline	*Aversive*	5.94	2.31
	Neutral	2.99	1.92
	Positive	5.37	2.39
Controlled Neutral	*Aversive*	5.88	2.20
	Neutral	2.86	1.816
	Positive	5.02	2.41
Resonance Frequency	*Aversive*	6.10	2.06
	Neutral	3.06	1.89
	Positive	5.24	2.33
Variable	*Aversive*	6.15	1.95
	Neutral	2.99	1.86
	Positive	5.26	2.32

PANAS. Participants did not demonstrate any appreciable change in general mood following breathing conditions. See Figure 6. A one-way ANOVA was performed to evaluate the relationship between breathing condition and the self-reported PANAS Positive scale. The ANOVA was not significant at the $\alpha = .05$ level, $F(3, 100) = 1.79$, $p = .152$. A one-way ANOVA was performed to evaluate the relationship between breathing condition and the self-reported PANAS Negative scale. The ANOVA was not significant at the $\alpha = .05$ level, $F(3, 100) = 1.46$, $p = .230$. The means and standard deviations are presented in Table 4 below.

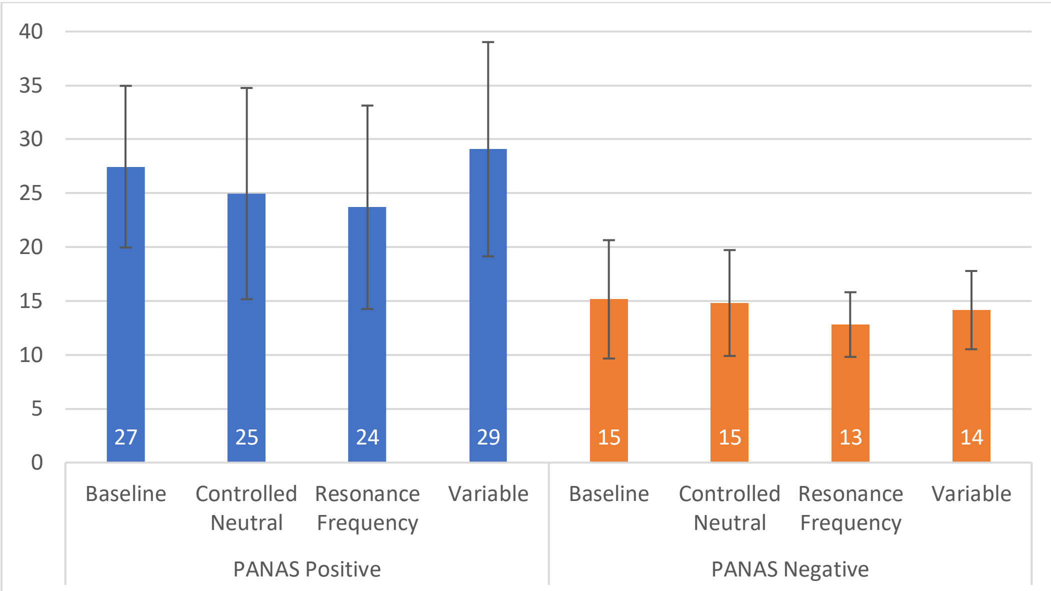

Figure 7 *Mean PANAS Positive and Negative Scores by Breath Condition*

Table 4
Descriptive Statistics for PANAS Positive and PANAS Negative Scores by Breath Condition

PANAS	*Breathing Condition*	*M*	*SD*
PANAS Positive	*Baseline*	27.46	7.50
	Controlled Neutral	24.96	9.80
	Resonance Frequency	23.69	9.44
	Variable	29.08	9.94
PANAS Negative	*Baseline*	15.15	5.49
	Controlled Neutral	14.81	4.91
	Resonance Frequency	12.81	3.00
	Variable	14.15	3.63

Physiologic Measures

Corrugator Supercilii. Participants demonstrated no consistent pattern of emotional expression in response to slide valence or breathing condition. A two-way ANOVA was performed to evaluate the effects of slide arousal and breathing condition arousal on tonic changes in muscle activity for the corrugator supercilii. The means and standard deviations for EMG of the corrugator supercilii are presented in Table 5 below.

The results indicated no significant main effect for slide arousal, F (2, 300) = .507, p = < .603, partial η2 = .003; no significant main effect for the breathing condition, F(3, 300) = .964, p = .410, partial η2 = .010; and no significant interaction between arousal and breathing condition, F(6, 300) =1.360 , p = .258, partial η2 = .009.

Table 5
Descriptive Statistics for Corrugator Supercilii in mV

Breathing Condition	*Slide Valence*	*M*	*SD*
Baseline	*Aversive*	.175	.474
	Neutral	.129	.316
	Positive	.122	.600
Controlled Neutral	*Aversive*	.108	.334
	Neutral	.089	.236
	Positive	-.508	3.388
Resonance Frequency	*Aversive*	.067	.265
	Neutral	.178	.457
	Positive	.136	.390
Variable	*Aversive*	.052	.369
	Neutral	.099	.274
	Positive	.197	.445

Zygomaticus Major. Participants demonstrated no consistent pattern of emotional expression in response to slide valence or breathing condition. A two-way ANOVA was performed to evaluate the effects of slide arousal and breathing condition arousal on tonic changes in muscle activity for the zygomaticus major. The means and standard deviations for EMG of the zygomaticus major are presented in Table 6 below.

The results indicated no significant main effect for slide arousal, F (2, 264) = .509, p = < .602, partial η2 = .004; no significant main effect for the breathing condition, F(3, 264) = .083, p = .969, partial η2 = .001; and no significant interaction between arousal and breathing condition, F(6, 264) =.898 , p = .343, partial η2 = .008.

Table 6

Descriptive Statistics for Zygomaticus Major in mV

Breathing Condition	*Slide Valence*	*M*	*SD*
Baseline	*Aversive*	.145	.360
	Neutral	.025	.1065
	Positive	.306	4.630
Controlled Neutral	*Aversive*	.122	.404
	Neutral	.074	.249
	Positive	.678	2.820
Resonance Frequency	*Aversive*	.339	.600
	Neutral	.176	.559
	Positive	.121	.425
Variable	*Aversive*	.383	.733
	Neutral	.046	.199
	Positive	.150	.443

Inhibition

Behavioral Measures

Response Time. Participants demonstrated differences in response time for breathing condition. See Figure 7. A one-way ANOVA was performed to evaluate the relationship between breathing condition and the response time during the Stop Signal task. The ANOVA was significant at the $\alpha = .05$ level, $F(3, 8632) = 3.51$, $p = .015$. Tukey's post hoc testing revealed significant differences between the controlled neutral and the resonance frequency breathing conditions, $p = .010$ and a trend-level statistic between the baseline and resonance frequency breathing conditions, $p = .086$.

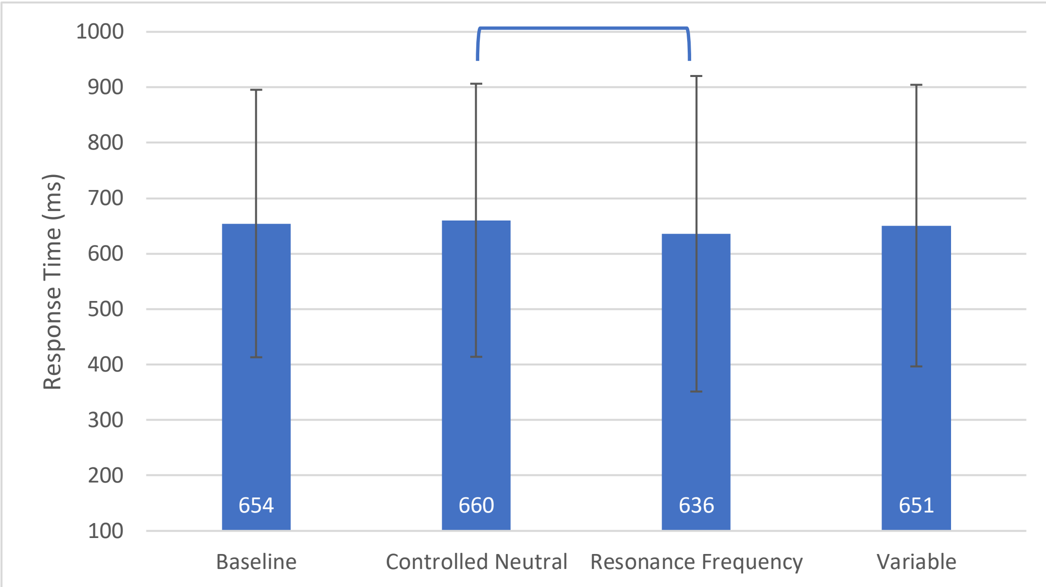

Figure 8 *Response Times in ms for Normal Stop Signal by Breath Condition.*

Note. Horizontal brackets note significant differences between bracketed trials, p = .010.

Accuracy. Participants also demonstrated differences in accuracy for breathing condition. See Figure 8. A one-way ANOVA was performed to evaluate the relationship between breathing condition and the accuracy of performance during the Stop Signal task. The ANOVA was significant at the $\alpha = .05$ level, $F(3, 4792) = 10.646$, $p < .001$. Tukey's post hoc testing revealed significant differences among the baseline and the resonance frequency breathing conditions, $p < .001$, the variable breathing condition, $p = .001$; and between the controlled neutral and resonance frequency breathing condition, $p = .005$. Means and standard deviations for Response Time and Accuracy are in Table 5.

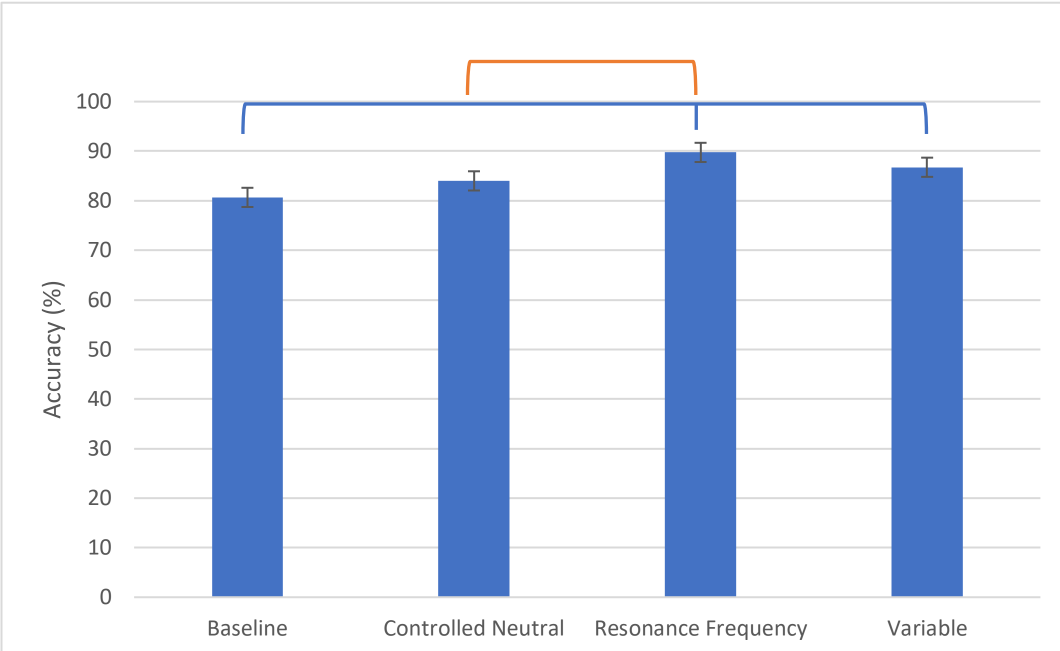

Figure 9 *Stop Signal Response Accuracy in Percentage by Breath Condition.*

Note. Horizontal brackets note significant differences between bracketed trials, $p < .01$.

Table 7
Descriptive Statistics for Response Time and Accuracy During the Stop Signal Task

Stop Signal	*Breathing Condition*	*M*	*SD*
Response Time (ms)	*Baseline*	654.30	241.20
	Controlled Neutral	660.16	246.24
	Resonance Frequency	635.86	284.52
	Variable	650.57	253.93
		Percentage	
Accuracy (% correct)	*Baseline*	80.67	
	Controlled Neutral	84.00	
	Resonance Frequency	89.75	
	Variable	86.75	

Control measures to ensure inclusion criteria and provide post hoc analysis

Self- Report Measures

Self-Evaluation of Breathing Questionnaire (SEBQ). The mean, range, and standard deviation of participant's SEBQ scores were evaluated and compared to results from recent literature (See Table 8; Courtney & van Dixhoorn, 2014; Mitchell et al., 2016). Participants SEBQ scores were within the expected range.

Table 8
Descriptive Statistics Comparison for the Self-Evaluation of Breathing Questionnaire

	Current Study (n= 26)	*Mitchell et al., 2016 (n= 180)*
Mean Score	17.31	15.5
Standard Deviation	8.92	11.5
Minimum Score	5	0
Maximum Score	36	*64*

Emotion Regulation Questionnaire (ERQ). The mean, range, and standard deviation of participant's ERQ scores were evaluated and compared to results from the literature (See Table 9; Gross & John, 2003). Participant's results were comparable to published norms.

Table 9
Descriptive Statistics Comparison for the Emotion Regulation Questionnaire

Emotion Regulation Strategy	*Group*	*Average of Mean Score*	
		Current Study	*Gross & John, 2003*
Cognitive Reappraisal	*Men*	4.91	4.60
	Women	4.94	4.61
Emotional Suppression	*Men*	3.80	3.64
	Women	3.06	3.14

Generalized Anxiety Disorder-7 (GAD-7). The mean, range, and standard deviation of participant's GAD-7 scores were evaluated to assess for level of anxiety in participants (see Table 10). 96.15% of participants scored within a minimal to moderate range. In light of the level of generalized anxiety in our sample and our within-participant design, we did not feel that anxiety was a confounding factor of concern.

Table 10
GAD-7 Results

		n	*Percent*
Severity Range	*Minimal (0-4)*	8	30.76
	Mild (5-9)	10	38.46
	Moderate (10-14)	7	26.92
	Severe (15-21)	1	3.85
Difficulty Rating	*Not Difficult at All*	3	11.54
	Somewhat Difficult	17	65.39
	Very Difficult	5	19.23
	Extremely Difficult	1	3.85

Discussion

Main Findings

In this study we examined the effects of breath manipulation on emotional and cognitive processes. We found statistically significant effects of breath pattern on response time and response accuracy in the inhibitory task. Specifically, resonance frequency breathing decreased response time and increased response accuracy. We did not find any significant relationships between breath pattern and self-report or physiological measures of emotional reactivity.

Emotional Reactivity

Self-Report Measures

Self-Assessment Manikin of Arousal and Valence (SAM-A and SAM-V). We hypothesized that participants would demonstrate no effect on valence by breath condition, given that a predictable relationship between respiration and valence has not been conclusively determined in past literature (Berry Mendes, 2016; Boiten, 1998; Boiten et al., 1994; Gomez et al., 2005; Lorig, 2016). However, we hypothesized that participants would demonstrate decreased arousal following resonance frequency breathing and increased arousal following variable breathing as compared to baseline and controlled neutral breathing. We found no significant effects of breathing condition on measures of emotion, including self-report of arousal (SAM-A) and valence (SAM-V). There are multiple factors that may have influenced these results, including breathing condition factors, emotion induction paradigm variables, and lack statistical power.

It is possible that the breathing patterns were not engaged long enough to have an emotional effect. It may be that the effects of breath condition on emotional reactivity occur over a longer time frame, such as days or weeks, as opposed to minutes. Studies that did show emotional and mood effects employed breathing from 28 days to up to 6 months (Balban et al., 2023; Erkkilä et al., 2021).

Additionally, resonance frequency breathing's effect on emotion could be moderated by its effect on increased cognitive functioning, it may be that resonance frequency breathing could indirectly promote the emotion regulation strategy of cognitive reappraisal, thus improving emotional reactions over a time. Furthermore, it is possible that the breathing conditions, notably variable breathing, may have been too cognitively demanding to allow for interoceptive awareness of bodily sensations and subsequent emotional effects. Participants were required to closely follow audio and video prompts in breathing, which could have distracted them from body awareness. Future studies may observe the effects of breath manipulation over time to both promote automaticity of breath patterns as well as explore the effects of a consistent breath manipulation practice on emotion.

Another explanation for our lack of significant results for our emotional reactivity condition is that the emotion induction paradigm might not have produced the intensity of emotional experience necessary to achieve our hypothesized effect. Nonetheless, we found a significant main effect for valence and arousal in response to the picture stimuli, which informs us that the stimuli produced the intended emotional effects. Picture-based emotion induction paradigm may not have produced a sufficient magnitude of emotional response, nor an emotional experience that lasted long enough for such an effect to be shown. The pictures were only shown for approximately five seconds each, and thus the participants may not have had enough exposure to elicit a strong emotional response. Future studies may employ other emotional induction paradigms such as mental imagery or emotional scripts may induce more robust and less transient emotional states.

In addition to presenting a potentially weak emotion induction technique, it is also possible that the study environment could have blunted emotional responses. To maximize attention to the study, participant sat in a dark, quiet audiology booth, which might have presented a secure environment where participants cognitively knew they were in a safe environment. Other emotion induction techniques such as mental imagery, visual and audio stimuli (video viewing), music listening, or autobiographical recall could reduce the effects of environment given their requirement to actively engage in an emotional response rather than passively accept an emotional stimulus (Siedlecka & Denson, 2019).

Finally, emotional response changes as a result of breathing condition might actually exist, but our measures of emotional experience may not be appropriate to detect such changes. Self-report measures and physiological measures of emotional expression might not be in the domain of measures sensitive to breathing condition. Other measures of emotional response such as physiological measures of arousal (e.g., electrodermal responses) or composite measures that include self-report, behavioral, and physiological measure may be necessary to detect such changes. Alternately, it is possible that there was an effect of breathing condition on emotional measures, but we have yet to reach statistical power to observe such changes.

Positive and Negative Affect Schedule (PANAS). In addition to transient mood states brought about by picture viewing, we hypothesized that participants would report higher levels of negative general mood following variable breath manipulation as measured by the Positive and Negative Affect Schedule as compared to the other breathing conditions. We found no significant effect on PANAS scores by breathing condition. However, visual inspection of the data reveals a consistent pattern by breath condition. Specifically, resonance frequency breathing appears to lower scores. Our findings are in line with Price and colleagues (2022) who used the

PANAS to assess affect in women with substance abuse disorder before and after resonance frequency breathing intervention. They found no significant differences in positive or negative PANAS sub scores either following resonance frequency breathing compared to a sham breath. However, they employed 57 in this study to achieve sufficient power. Our study requires more power is needed to determine if this pattern is significant.

As mentioned, in regard to the SAM-A and SAM-V results, it is possible that this lack of finding is due to inadequate breath manipulation duration or timeframe, or an effect from increased cognitive load during the breathing tasks.

Physiologic Measures

Surface Electromyography of Corrugator Supercilii and Zygomaticus Major. We hypothesized that resonance frequency breathing would result in a decrease in tonic muscle activity of the corrugator supercilii during aversive picture viewing. We hypothesize a stable or increased activity in the zygomaticus major positive picture viewing, given that resonance frequency breathing might mitigate results if its effect on emotion was largely arousal-based. Conversely, we hypothesized that variable breathing would result in an increase in tonic muscle contraction of the corrugator supercilii and stable or reduced activity in the zyogmaticus major. We found no significant differences in tonic muscle activation for any breath condition. Thus, our physiological measures of emotional expression might reflect no such relationship between breathing conditions and emotional experience. However, it could be that the factors that influenced null finding in self-report measures, such as an inadequate emotional induction paradigm, inadequate breath manipulation duration and timeframe, lack of statistical power, or any combination of these, also influence physiological measures of emotional expression. Other factors that might also explain our lack of findings include the high level or variability in these measures. More sophisticated data processing techniques, such as the removal of noise in the data from electrode leakage, specifically, removing heart rate signal from the data, or a tighter segmentation of the data to only include the first 3000 milliseconds where initial reactions are thought to be greater might reveal an effect of breathing condition on emotional expression.

Inhibitory Control

Behavioral Measures

Response Time and Response Accuracy. We hypothesized that resonance frequency breathing would result in a decrease in response time and an increase in response accuracy in the Stop Signal Task, indicating an increase in inhibitory modulation and control. Conversely, we hypothesized that variable breathing would result in an increase in response time and a decrease in response accuracy in the Stop Signal Task, indicating a decrease in inhibitory control. Our study partially confirmed this hypothesis with a statistically significant reduction in response time following resonance frequency breathing as compared to controlled neutral breathing. There was also a trend-level statistic in response time between baseline and resonant frequency breathing. However, we did not find an increase in response time for the variable breathing condition, suggesting that variable breathing effects might be observed in response accuracy, rather than response time. Indeed, we observed that variable breathing also had a reduction in response time, albeit not significant, showing the second shortest response time among breathing conditions. If the variable breathing condition was successful in mimicking increased stress or anxiety, it stands to reason that the reduced response times might reflect a hypervigilant system causing responses to be quick. Also, the lack of significance might be due to the high variability in response time. However, the difference between resonance frequency breathing and variable breathing might not be in the timing of response but the accuracy of those responses. Response time decreases are only as useful as their accuracy. Thus, the value-added in response time is contingent upon whether or not those responses are accurate.

We found statistically significant differences in response accuracy between baseline and variable breathing, baseline and resonance frequency breathing, and controlled neutral and resonance frequency breathing. Overall, resonance frequency breathing resulted in the fastest response times and highest response accuracies. This is an intriguing result as intuitive thinking would predict that the faster one responds, the more prone one is to error. However, it appears that the effects of resonance frequency breathing not only preserved but improved accuracy despite faster response times.

Notably, the variable breathing condition produced that second highest accuracy scores, which is not in the direction of our overall hypothesis. It could be that variable breathing increases vigilance, and this increased in vigilance has an effect on response accuracy as well. If variable breathing, which proports to mimic and even produce anxiety in an individual, increases responsiveness within an organism, it demonstrates the adaptive nature of anxiety and vigilance. Future studies looking at the detrimental cognitive effects of anxiety as triggered by variable breathing should include different levels of anxiety to verify if there is an optimal amount of vigilance for functioning and how this optimal level compares to resonance frequency breathing.

Our results are partially consistent with a study which examined the effects of slow-paced breathing on inhibition, working memory, and cognitive flexibility. Laborde and colleagues (2022) examined the effects of a breath similar to resonance frequency breathing, which they termed “slow-paced breathing”, which consisted of 6 cycles per minute with 4.5 second inhales and 5.5 second exhales. For inhibitory assessment, they utilized a color word matched Stroop task and measured both response time and accuracy. Unlike our study, they found no effect on

Stroop response time following slow-paced breathing. Similar to our study, they did find a significant increase in Stroop accuracy following slow-paced breathing. Beyond inhibitory abilities, they found a significant effect for working memory and cognitive flexibility.

Overall, results of cognitive changes as a result of breathing manipulation are of interest for a few reasons. Decreases in response time have been suggested to indicate increases in other aspects of cognitive functioning, notably memory, verbal fluency, and processing speed (Prabu Kumar et al., 2020). While our data corroborate these suggestions (as evidenced by increased response accuracy following resonance frequency breathing), it is interesting to note that many participants indicated that they felt “tired” or “sleepy” following resonance frequency breathing. A fatigued state is counterintuitive considering the significant decreases in response time and increases in response accuracy, both of which indicate high levels of alertness. Therefore, it is possible that the participants were experiencing an altered cognitive state for which they had no suitable descriptive term, and thus landed on “tired.” Alternatively, resonance frequency breathing might have produced an optimal state of being, sometimes referred to as “being in the zone” or a flow state that is achieved by elite athletes or by engaging in challenging skills (Csikszentmihalyi, 1990). Resonance frequency breathing might induce this state, without the necessity of increased physical activity, and could prove useful to individuals with limited time or mobility to achieve this state.

Implications for Clinic

Prior to delving into potential clinical implications of breath manipulation, it is important to distinguish between breath manipulation and breath retraining. Prior to imposing a manipulated breath pattern, clients must possess a respiratory system that is flexible enough to handle the demands of an imposed breath pattern. Therefore, prior to any breath manipulation, it is necessary to address baseline breath patterns and improve respiratory function through increasing respiratory flexibility (Courtney, 2009). Once a functional and flexible respiratory system has been established, use of breath manipulation may have notable benefits for behavioral rehabilitation of communication and swallowing disorders (Golan et al., 2023).

If we follow the logic that decreased response times are indicative of increased cognitive functioning in the realms of memory, verbal fluency, and processing speed, it stands to reason that, when training these skills, beginning therapy sessions with five minutes of resonance frequency breathing would increase cognitive skills. The optimized cognitive states induced by changing breathing behavior could improve the efficacy of behavioral interventions. Therefore, clinicians who address cognitive functioning, who are not typically familiar with breath retraining or manipulation, may consider beginning sessions with breath manipulation to improve their client's cognitive state for therapy. Although each individual has an optimal resonance frequency breath rate based on their own anatomy and physiology, people may find effects at rates near their resonance frequency (Fisher & Lehrer, 2022; P. M. Lehrer et al., 2020; Vaschillo et al., 2006). In fact, many studies simply select a resonance frequency breath rate of 0.1 Hz (6 breaths per minute) for all subjects, and such studies have found similar results to those who have specifically determined individual resonance frequency breath rates (Laborde, Allen, Borges, Hosang, et al., 2022; Leganes-Fonteneau et al., 2021; Price et al., 2022). Thus, a generic rate of 10 second cycles (5 second inhales and exhales) is recommended in situations where access to instrumentation is limited or for those who cannot obtain a specific rate for themselves.

The clinical use of resonance frequency breathing, in the context of speech language therapy, comes with cautions. Because changing breathing behavior changes autonomic homeostasis, those changes in homeostasis might require time, as observed in heat acclimatization (Pandolf, 1998). It might take multiple sessions to acclimate to resonance frequency breathing. Thus, clinician support and guidance are encouraged. Furthermore, given the myriad of medical conditions that affect the cardiopulmonary system, certain breathing behaviors, such as resonance frequency breathing, may not be ideal breath patterns for some patients. Therefore, additional clinician training that includes the psychological and physiological effects of breath manipulation is warranted so that optimal breath manipulation patterns are selected for each individual client.

Limitations and Future Directions

Study Design

A clear limitation of this study is the study size. Many of our hypotheses were not confirmed due to null statistical findings. Future plans for this research include continuing data collection until calculated power-levels are achieved. A secondary limitation of this study is the make-up of the participant pool, which was primarily convenience sampling due to logistical constraints. Future plans for this line of research should include recruitment strategies that include a wider demographic participant pool that include participants of different ages, educational abilities, temperaments, and health conditions. For example, all of the participants in this study had healthy respiratory systems, so findings of this study can only be applied to a small demographic, which might not apply to a typical patient population. It is unclear if results in this study would hold for people with respiratory diseases or disorders.

Breathing Conditions

It is possible that the controlled neutral and variable breath patterns were not reflective of rest breathing and anxious breathing, respectively. Following controlled neutral breathing, some participants noted feeling that 16 breaths per minute felt fast, and a few had to be reminded to take less deep breaths during the controlled neutral breathing as they were reporting symptoms of hyperventilation (e.g., tingling fingers).

The variable breathing was composed of random arrangements of hyperventilation, apnea, sighs, and a sniff-sniff-sigh pattern. Recent literature has suggested that sighing, especially cyclic sighing (inhale-inhale-sigh) may reduce physiologic arousal and enhance mood (Balban et al., 2023; Vaschillo et al., 2015). Therefore, it is possible that the inclusion of sighing and cyclic sighing may have impeded the effects of the hyperventilation and apneic periods. Furthermore, it is possible that the variable breathing was too cognitively demanding, resulting in attentional resources being diverted from interoceptive awareness. Participants may have experienced a cognitive separation between the breathing task and their emotional experience. In other words, they may have dissociated from their emotional experience in favor of completing the task accurately. Future studies may seek to remove sighing and cyclic sighing from the variable breath pattern, which may further serve to reduce its complexity, subsequently reducing cognitive load during the variable breathing task.

Emotion Induction Paradigms

As previously mentioned, a potential limitation of this study includes the method of emotion induction via picture stimuli. Future studies may seek to utilize methods which generate stronger and longer lasting emotional responses, such as mental imagery, standardized or personalized emotional scripts, movie watching, or music listening. Additionally, future studies might wish to separate out emotional and cognitive conditions to control for the influences that one condition may have on the other. Engaging in cognitive tasks between emotion induction tasks might have reduced the overall effect of the emotion induction.

Conclusions

This study investigated the effects of three different breathing patterns on emotional processing and task inhibition. Breathing conditions included a controlled neutral condition designed to mimic a typical rest breathing pattern, a resonance frequency breathing condition that included slow, even, cyclical breathing, and a variable breathing condition patterned after breathing commonly seen during episodes of acute anxiety. Results suggested that emotional processing did not significantly differ according to breathing conditions. However, breathing conditions did have an influence on response time and accuracy during an inhibitory task. Resonance frequency breathing resulted in reduced response time and increased response accuracy, suggesting that this breathing technique might have important clinical utility.

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IRB Approval

This study was approved by the University of Memphis Institutional Review Board on August 13, 2022 (PRO-FY2022-522).