# What Resonates with you? Methods of Induced Cardiovascular Resonance

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Thesis submitted to the faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

In

Psychology

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April 26th, 2010

Blacksburg, VA

Keywords: Cardiovascular, Resonance, Respiration

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## ABSTRACT

Patients with autonomic dysfunction have benefited from balancing of parasympathetic and sympathetic activity through the practice of slow breathing exercises. In preliminary studies, patients with various autonomic dysfunctions used biofeedback of respiratory activity to slow breathing to a cadence of six cycles per minute, a frequency known as the *resonant frequency* (Vaschillo, Vaschillo, & Lehrer, 2006). Breathing at this rate produces *cardiovascular resonance* (large oscillations in heart rate and blood pressure), forcing the autonomic nervous system to continuously regulate these changes, thereby exercising, and eventually strengthening autonomic control over hemodynamic events. The present study examined several methodologies, such as slow breathing exercises, which are believed to strengthen autonomic control by inducing cardiovascular resonance. Specifically, the current experiment compared different methods of inducing cardiovascular resonance, such as paced breathing and biofeedback assisted protocols. The utility of positive emotion inductions to attenuate respiratory discomfort during slow breathing exercises was also examined. Accurate estimation of the resonant frequency using respiratory methods was largely unsuccessful. However, all respiratory methods produced profound effects in the cardiovascular system, with some differences in the magnitude of effect. In addition, the utility of an emotion induction during slow paced breathing was also demonstrated. The results of this study also support the notion that slow breathing improves pulmonary gas exchange efficiency, in addition to strengthening the baroreflex, by increasing heart rate variability.

# DEDICATION

I dedicate this thesis to my father, Dennis Hurston Allen, who is with me always.

ACKNOWLEDGMENTS

I would like to recognize Dr. Bruce Friedman, my mentor, my advisor, my sensei.

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# INTRODUCTION

The autonomic nervous system (ANS) has been of interest to scientists since Galen's notion of visceral sympathy regarding the sympathetic ganglion (Ackerknecht, 1974). One division of the ANS, the sympathetic nervous system (SNS), is responsible for mobilizing and metabolizing the body's resources by increasing cardiac output and dilating the bronchioles and pupils. Another division of the ANS, the parasympathetic nervous system (PNS), conserves the body's energy by decreasing cardiac output and increasing digestion. SNS activity is useful, when exercising, for example, but chronic SNS activity is a risk-factor for cardiovascular disease and is related to increased mortality (Curtis & O'Keefe, 2002). Preliminary studies of patients with cardiovascular disease and autonomic dysfunction in general have shown beneficial effects from interventions such as physical exercise, which increases PNS activity and attenuates SNS activity (Pietilä et al., 2002).

Patients with autonomic dysfunction have also benefited from a balancing of parasympathetic and sympathetic activity through slow breathing exercises (Hassett et al., 2007; Karavidas et al., 2007; Lehrer et al., 2003; Nolan et al., 2005). In preliminary studies, patients with various autonomic dysfunctions used biofeedback of respiratory activity to slow breathing to a cadence of six cycles per minute, a frequency known as the *resonant frequency*. Breathing at this rate produces *cardiovascular resonance* (large oscillations in heart rate and blood pressure), forcing the autonomic nervous system to continuously regulate these changes, thereby exercising and eventually strengthening autonomic control over hemodynamic events.

The present study examined several methodologies that putatively strengthen autonomic control by inducing cardiovascular resonance. Specifically, the methods of paced breathing and biofeedback assisted protocols were compared. Both methods include breathing at six breaths

per minute, which can be difficult for individuals to maintain. Therefore, the present study also examined the utility of positive emotion inductions to attenuate respiratory discomfort during slow breathing exercises.

*Cardiovascular Resonance*

Comprehension of the general concept of resonance is required to understand how slow breathing protocols induce resonance in the cardiovascular system. A classic example of resonance is being pushed on a swing. The push must be in rhythm with the swinger's momentum. Resonance between the natural swinging motion and the applied force makes the swing go higher than before. The same methodology can be applied to the cardiovascular system by breathing at a rate which resonates with inherent rhythms in heart rate.

Fluctuation in heart rate related to respiration is known as *respiratory sinus arrhythmia* (RSA; Angelone, & Coulter, 1964). During inhalation, heart rate tends to increase, and during exhalation heart rate decreases. Previous research has found that if respiration rate is slowed to about six breaths per minute (0.1 Hz), the pattern of RSA overlaps with inherent 0.1 Hz oscillations in heart rate related to blood pressure modulation (Vaschillo, Vaschillo, & Lehrer, 2006). The point at which these low frequency oscillations overlap with RSA is known as the resonant frequency because the two signals summate and produce large variations in heart rate.

Heart rate variability has been an aim of treatment studies due to its profound relation to various physical and mental health outcomes. For example, heart rate variability biofeedback has recently been used to assist treatment of autonomic dysfunctions associated with coronary heart disease, asthma, fibromyalgia, posttraumatic stress disorder, and depression (Hassett et al., 2007; Karavidas et al., 2007; Lehrer et al., 2003; Nolan et al., 2005; Zucker et al., 2009). Patients in these studies were instructed to slow their respiration to about six breaths per minute

(0.1 Hz) while trying to maximize oscillations in their displayed heart rate. Previous research has shown heart rate variability increases as respiration rate decreases and that this effect plateaus at about 6 breaths per minute, the rate which produces resonance, or maximal increases in heart rate variability (Hirsh & Bishop, 1981).

*Cardiovascular Resonance as a Treatment of Autonomic Dysfunction*

Why should treatment of autonomic dysfunction focus on cardiovascular resonance? Treatments which utilize paced respiration and biofeedback to induce large oscillations in heart rate and blood pressure have been shown to strengthen the baroreflex system (Lehrer, 2003). The underlying theory is that fluctuations in blood pressure activate stretch receptors, known as baroreceptors, in the aortic arch and carotid arteries, which elicits autonomic modulation of heart rate to balance changes in blood pressure. This feedback loop, also known as the baroreflex, enables cardiovascular stability and flexibility by exciting or inhibiting parasympathetic and sympathetic activity as needed. Stronger autonomic control over the cardiovascular system increases the body's ability to handle a variety of cardiac changes induced by affective and environmental events (Berntson, Norman, Hawkley, & Cacioppo, 2008).

One index of the regulatory power of the ANS is RSA, which originates from neural pathways in the nucleus ambiguous and regulates beat-to-beat changes in heart rate (Porges, 2007). The nucleus ambiguous has also been shown to be critical for the baroreflex (Cheng, Zhang, Yu, Wurster, & Gozal, 2004). The relation between the baroreflex and vagal pathways are important when considering methods of treating autonomic dysfunction. For example, patients with chronic heart failure have used slow breathing exercises with short-term effects on the baroreflex similar to captopril, an angiotensin-converting enzyme inhibitor used in the treatment of hypertension (Bernardi et al., 2002).

Many patients with autonomic dysfunction would logically benefit from a treatment that increases their ability to adapt to physiological change. For example, cardiac patients with stronger baroreflexes have been shown to recover faster from myocardial infarctions (Rovere et al., 1998). Asthmatics have benefited from cardiovascular resonance therapy by improving autonomic control and attenuating vagal hyperactivity during asthma attacks (Lehrer et al., 2003). However, therapies which induce cardiovascular resonance are relatively new, and standardized treatment protocols are still being developed.

*Resonant Frequency Measurement*

Vaschillo et al., (2006) outline a procedure to assess and stimulate an individual's cardiac resonant frequency. The person must first breath at five different respiration rates (4.5, 5.0, 5.5, 6.0, and 6.5 breaths/minute) for 2 minutes each. The inter-beat intervals (IBI) between consecutive R spikes in the electrocardiogram (ECG) are recorded for each 2-minute segment and analyzed in the frequency domain using spectral analysis. The respiration rate which yields maximal spectral power in the low frequency range (0.04 – 0.15 Hz) is regarded as the cardiac resonant frequency. Following estimation of the resonant frequency, each individual is instructed to breathe at this rate so as to induce cardiovascular resonance and maximize heart rate variability.

Clinical studies have included measurement and stimulation of the cardiac resonant frequency once a week for ten weeks (Hassett et al., 2007; Karavidas et al., 2007). The first three sessions are sometimes marked by subjects breathing too deeply, causing an excessive increase in tidal volume and decrease in end-tidal carbon dioxide, which often leads to hyperventilation and anxiety. These complications dissipate gradually and are absent by the fourth week. Speculations have been made that breathing complications and accompanying

psychological factors add error to resonant frequency estimation, and likewise to stimulation at the proper frequency (Vaschillo et al., 2006).

The correlation between height and calculated resonant frequency is a good measure of this error in estimation because of the dependence upon anatomical factors such as length of vasculature and speed of neural transmission (Vaschillo et al., 2006). The taller the subject, the longer it takes for blood to circulate, and the slower the respiration rate required to produce maximal heart rate variability. Inaccuracies are reflected in the correlations between the height of a subject and their resonant frequency calculated from each of the 10 sessions (Vaschillo et al., 2006). The magnitude of the correlation between height and resonant frequency dramatically increased from low to moderate after the third session of heart rate variability biofeedback. The pattern of correlations indicates a sudden rather than gradual change in assessment of resonant frequency.

*Explanations of Error in Resonant Frequency Measurement*

Many of the pilot studies using the 10-week heart rate variability biofeedback paradigm have shown beneficial effects by the 4th session (Hassett et al., 2007; Karavidas et al., 2007; Lehrer et al., 2004). However, the possible explanations for these findings are manifold. One methodological issue is that the first three sessions utilize paced breathing to assess the resonant frequency. Beginning with the fourth session, paced breathing is replaced with a biofeedback method of estimating the resonant frequency. Subjects are given feedback about their heart rate and respiration rate and asked to maximize high amplitude oscillations in heart rate. It may be possible to obtain valid resonant frequency estimates prior to the fourth session if paced breathing is eliminated altogether and only biofeedback is used at the onset of treatment.

Alternatively, inaccurate resonant frequency calculations in the first three sessions may be a function of the patient's level of comfort with breathing at slow respiration rates, rather than an inherent characteristic of paced breathing. Perhaps patients experienced more negative affect in the early sessions due to unpleasant perceptions of an uncomfortable breathing task. Evidence for this hypothesis has been demonstrated by patients reporting more unpleasant side effects during the first three sessions of the ten week treatment (Lehrer et al., 2003). Therefore, one approach to improve heart rate variability biofeedback is to reduce sources of negative affect associated with slow, uncomfortable breathing.

Dyspnea (i.e. the perception of uncomfortable breathing), can vary along valence (hedonic) and arousal (intensity) continua (American Thoracic Society, 1999). Dyspnea has been shown to be perceived as less unpleasant during positive affect inductions compared with neutral or negative inductions (von Leupoldt, Mertz, Kegat, Burmester, & Dahme, 2006). Induced positive affect might minimize negative affect and perceived unpleasantness during induced cardiovascular resonance. Coupling paced breathing or biofeedback with positive affect inductions (pictures, music, or film) should attenuate unpleasant side effects and increase the validity of the estimated resonant frequency and improve heart rate variability biofeedback treatments in general.

*Aims of the Current Study*

The first aim of the present experiment was to examine the validity of various methods of determining a person's resonant frequency. Also, the accuracy of paced breathing in estimating the resonant frequency may be improved if negative emotions and perceptions of dyspnea are ameliorated. Positive affect inductions have been shown to reduce negative perceptions during difficult breathing tasks (von Leupoldt el al., 2006) and should diminish unpleasantness

associated with paced breathing at slow frequencies (Vaschillo et al., 2006). Based on this underlying theory, the following hypotheses were tested:

1. Biofeedback is more accurate than paced breathing when estimating the resonant Hz.
2. A positive affect induction would increase the accuracy of paced breathing estimations of the resonant frequency to a level similar to biofeedback.
3. Compared to the regular paced breathing task, the combination of paced breathing with the emotion induction are viewed as more pleasant and induce fewer reported perceptions of dyspnea.

The necessity of ameliorating dyspnea and negative affect during paced breathing might be bypassed by assessing the resonant frequency using non-respiratory methods. Vaschillo et al., (2008) recently demonstrated cardiovascular resonance when emotional pictures were presented at a rate of 5-seconds on, 5-second off (0.1Hz). Based on this recent finding, a fourth and final hypothesis was tested:

4. Paced visual stimuli (0.075 – 0.108 Hz), can be used to assess the cardiac resonant frequency with comparable accuracy to respiratory methods.

The second aim of the present experiment was to observe differences in autonomic state during various methods of induced cardiovascular resonance. There is a paucity of research on cardiovascular resonance measuring multiple autonomic variables. Of particular interest is how the various methods affect arterial blood oxygen saturation. Some theorists believe that one of the functions of respiratory sinus arrhythmia is to increase pulmonary gas exchange efficiency (Giardino, Glenny, Borson, & Chan, 2003; Hayano, Yasuma, Okada, Mukai, & Fujinami, 1996). Due to the fact that resonant stimulation of the heart increases heart rate variability, one might expect an increase in oxygen saturation if pulmonary gas exchange efficiency also increases.

Also of interest are the effects of the breathing protocols on gastric motility. Parasympathetic activity increases the amplitude of normal stomach contractions (Muth, Thayer, Stern, Friedman, & Drake, 1998). Changes in gastric motility induced by the breathing protocols may offer a clearer picture of how the autonomic nervous system is being affected.

The third and final aim was to test the hypotheses listed above for gender differences. Some reports have shown women are more strongly affected by negative affect inductions, while men are more strongly affected by positive affect inductions (Bradley, Codispoti, Sabatinelli, & Lang, 2001). Gender differences, as well as the other aims and hypotheses, were examined using a picture viewing task, a biofeedback task, and two paced breathing tasks. The resonant frequencies determined during each task were compared to index the validity of each method. One paced breathing task was combined with a positive affect induction while the other paced breathing task was not. Comparison of the two paced breathing tasks permitted examination of the role emotion might play during cardiovascular resonance.

## METHOD

### *Subjects*

College students were recruited using the Virginia Tech SONA system, an online experiment management system designed to help students sign up for experiments in exchange for extra credit in their classes. Subjects were asked via email to refrain from caffeine, alcohol, and exercise at least twelve hours prior to the experiment, to not smoke two hours before the experiment, and to avoid eating at least one hour before the experiment. Of the 80 subjects who completed the study, physiological data were lost for four subjects due to equipment failure, and five subjects were excluded because they failed to breathe at the prescribed respiration rates during the paced breathing tasks. The remaining 71 subjects (36 male; mean age = 20.08 years,

SD = 1.83) were not screened for any mental or health conditions because the experiment investigated a breathing protocol often used in the treatment of various mental and medical maladies. However, for descriptive purposes, subjects answered a series of questions on a computer-based questionnaire which indexed their physical and mental health status.

Many of the subjects reported relevant medical and physical conditions. Smoking behaviors were reported by a small segment of the sample: 80.3% were non-smokers, 7% smoked once a month, 5.6% smoked once a week, 1.4% smoked once a day, and 5.6% smoked four or more times a day. Asthma was reported by 18.3% of the sample, 1.4% reported lung problems, and 1.4% reported cardiovascular disease. The average body mass index (BMI; calculated as (weight (kg) ÷ [height (m)$^2$]); mean = 24.85, SD = 3.72) was on the upper edge of the normal range, although a large portion of the sample was either overweight or obese (56.3% normal; 35.2% overweight, and 8.5% obese). As such, BMI was correlated with all physiological change scores to detect any physiological relationship between body composition and the physiological effects of the each task. Results were reported when significant effects were found. Correlations with asthma and smoking behaviors were not conducted because only a small portion of the sample reported having asthma or smoking more than once a week.

*Procedure*

Upon arrival, subjects completed an informed consent form and a questionnaire composed of mental and physical health questions. Each subject was then weighed in pounds (lbs) and measured in centimeters (cm) using a mechanical column scale. All electrode sites were cleaned with an alcohol preparation (except those designated for skin conductance). Continuous physiological recording commenced once the subject was properly connected and seated.

*Tasks*

*Biofeedback and paced breathing vs. biofeedback only.*

Two experimental tasks tested the hypothesis that paced breathing is related to errors in estimation of the resonant frequency. The first task entailed heart rate variability biofeedback with paced breathing, similar to the protocol followed during the first three sessions of the 10-week treatment paradigm discussed earlier (Vaschillo et al., 2006). Subjects were given visual feedback on a computer screen of their heart rate and respiration and asked to breath with a pacing stimulus (moving bar graph) while maximizing the peak-to-trough amplitude in their heart rate. The task consisted of paced breathing at five frequencies (4.5, 5.0, 5.5, 6.0, and 6.5 times per minute; order counterbalanced) for three minutes each. To control for length of inspiration and expiration during each of the breathing rates, inspiration length constituted 45% of each breath length and expiration 55%. The biofeedback only task consisted of five minutes of biofeedback without a pacing stimulus. Subjects were asked to breath in phase with their heart rate while maximizing the peak-to-trough amplitude in their heart rate. Baseline and recovery periods of three minutes preceded and followed each task.

*Paced Picture Presentation.*

The paced picture presentation (IAPS; Lang, Bradley, & Cuthbert, 2001) tested the hypothesis that the resonant frequency can be estimated and stimulated independent of respiratory manipulations. The paced picture presentation task consisted of five 3-minute picture series (IAPS; positive valence) paced at each of the five frequencies used in the paced breathing task (4.5, 5.0, 5.5, 6.0, and 6.5 times per minute; order counterbalanced). The pictures were selected from six categories (adventure, erotica, family, food, nature, & sports) and were regarded as relatively positive. Pictures turned on and off at each frequency using the same ratio

used in the paced breathing task (picture off 45% of the time, picture on 55% of the time). The resonant frequency was determined as the picture presentation rate which produced the highest amplitude oscillations in heart rate. Baseline and recovery periods of three minutes preceded and followed the task.

*Paced breathing with induced emotion.*

The paced breathing task with induced emotion used the picture presentation task (described above) as the pacing stimulus to test the hypothesis that complications associated with slow breathing can be ameliorated with positive affect. Subjects were instructed to inhale when a picture turns off (black screen) and exhale when a picture turns on. Five 3-minute picture series' were presented at five frequencies (4.5, 5.0, 5.5, 6.0, and 6.5 times per minute). Pictures in this task turned on and off at each frequency using the same ratio used in the paced breathing task (picture off 45% of the time, picture on 55% of the time).

*Laboratory Questionnaires*

Affect was measured following each task using the Self Assessment Manikin (SAM; Morris, 1995). Subjects were asked to rate their experienced arousal and perceived pleasantness during each task on a 9-point scale ranging from 1 (low arousal / unpleasant) to 9 (high arousal / pleasant). Perceived dyspnea (i.e. the perception of uncomfortable breathing) was measured following every task, except the paced picture presentation, which included no respiratory manipulation (American Thoracic Society, 1999). Subjects were asked to rate the intensity and unpleasantness of dyspnea using a scale ranging from 0 (not noticeable / not unpleasant) to 10 (maximal imaginable intensity / maximal imaginable unpleasantness; see Appendix C).

*Study Design*

The experiment followed a within-subjects design. The paced picture presentation task was always the first task completed so as to minimize intentional respiratory modulations similar to the other tasks. The three breathing tasks (paced breathing, paced breathing with the emotion induction, and biofeedback), the order of the five paced breathing rates in the two paced breathing tasks, and the questionnaire order (dyspnea and affective questions) were all counterbalanced across subjects. Two picture sets were used in the experiment so that a different set of pictures was used for the picture presentation task and paced breathing with the emotion induction. The order of the two picture sets was also counterbalanced across subjects. The duration of the entire experiment was two hours.

*Apparatus*

Impedance pneumography, pulse oximetry, and electrogastrography were recorded using a BIOPAC MP100 system (BIOPAC Systems Inc, Goleta, CA). Electrocardiography, skin conductance, and respiratory activity were recorded using a BIOPAC MP36 system. All raw signals were digitized at 1,000 Hz and analyzed with AcqKnowledge 4.1 software (BIOPAC Systems Inc, Goleta, CA). All physiological data were analyzed from the last two minutes of each task.

*Electrocardiography (ECG)*

ECG was recorded by placing two thoracic electrodes placed in a modified II lead configuration on the chest across the heart. The ECG was analyzed online to derive IBI's for a real-time display of heart rate during the biofeedback and paced breathing tasks. ECG was also analyzed offline to derive IBI's and metrics of heart rate variability. Heart rate variability was calculated to quantify large oscillations in heart rate which are one of the characteristics of

cardiovascular resonance. As heart rate variability is often quantified using many different metrics, heart rate variability was analyzed in both the frequency and time domain.

To quantify heart rate variability in the frequency domain, the time series of inter-beat intervals for each task was analyzed using autoregressive modeling (AR; Berntson et al., 1997). Power spectral density estimates were calculated for three frequency bands: low frequency (LF; 0.04–0.15 Hz), high frequency (HF; 0.15–0.5 Hz), and the resonant frequency band (0.075–0.108Hz). Variability in the LF band is traditionally viewed as indicative of changes in heart rate related to blood pressure modulation (Akselrod et al., 1985), while the HF band represents fluctuations in heart rate related to parasympathetic activity at the frequency of respiration (Cacioppo et al., 1994). In the present experiment, respiratory related changes in heart rate during slow breathing tasks were quantified using the LF band, as respiratory rate was within this frequency range. The resonant frequency range (≈ .1Hz) is a novel frequency band recently shown to be sensitive to emotional and autonomic regulation in the context of stimulation at six cycles per minute (Vaschillo et al., 2008).

Four time domain metrics of heart rate variability were included. Root mean square of successive differences (RMSSD) is a metric of relatively fast, beat-to-beat changes in heart rate related to vagal modulation (Friedman, Allen, Christie, & Santucci, 2002). RMSSD was quantified as:

$$RMSSD = (\sum (IBI_{J+1} - IBI_J)^2) \wedge^{1/2}$$

, where $\sum (IBI_{J+1} - IBI_J)^2$ represents the average of the squared successive differences between consecutive IBI's. Percentage of successive differences in IBI's greater than 50 msec (pNN50) is also a metric of relatively fast changes in heart rate due to parasympathetic activity (Ewing, Neilson, & Travis, 1984), and was quantified as:

$$\text{pNN50} = \frac{\text{\# of successive difference between consecutive IBI's} \geq 50 \text{ msec}}{\text{Total \# of IBI's - 1}}$$

The standard deviation (SD) of the time series of IBI's was calculated to determine the total amount of variability in heart rate over the course of three minutes, regardless of the speed of the changes (Malik et al., 1996). SD of IBI was quantified as:

$$\text{SD of IBI} = (\sum(\text{IBI}_J - \text{IBI}_\mu)^2) \wedge {}^1/_2$$

, where $\sum(\text{IBI}_J - \text{IBI}_\mu)^2$ represents the sum of squared deviations from the average IBI. Heart rate variability was also quantified using the peak-to-valley method by subtracting the minimum heart rate during expiration from the maximum heart rate during inspiration (Grossman, van Beek, & Wientjes, 1990). The peak-to-valley metric is unique from the other time domain measures in that heart rate variability is quantified on a breath-by-breath basis using a separate measure of respiration as a guide.

*Respiration Strain Gauge*

Respiratory rate was quantified using a strain gauge around the thoracic area. Expansion of the strain gauge was converted into an online digital signal for real-time display of respiratory activity during the biofeedback and paced breathing tasks. A strain gauge was used for real-time quantification of respiratory activity because it requires minimal digital filtering and is easily converted into an online visual display of respiratory activity. However, respiratory activity derived from the strain gauge was not used in offline statistical analyses because the strain gauge sometimes loosened during the recording and deteriorated measurement of breathing depth.

*Impedance Pneumogram (IPG)*

To improve upon the respiratory recording from the strain gauge, IPG was collected using a four spot impedance electrode array. IPG measures changes in thoracic impedance due

to respiration, from which respiration rate, tidal volume, and minute ventilation can be derived (de Geus, Willemsen, Klaver, & van Doornen, 1995; Ernst, Litvack, Lozano, Cacioppo, & Berntson, 1999; Houvteen, Groot, & de Geus, 2006). Respiration rate was quantified as breaths per minute (BPM = 60 / the average duration of the respiratory cycle duration). Tidal volume was quantified as the average absolute difference between the maximum and minimum change in impedance during each breath cycle and is indicative of the amount of air inhaled with each breath. Minute ventilation was quantified as the product of respiration rate and tidal volume and is a metric of the amount of air inhaled and exhaled each minute. Respiratory rate, tidal volume, and minute ventilation were collected to provide a dynamic view of respiratory activity throughout the experiment.

*Skin Conductance (SC)*

SC was collected from the middle and index finger of the left hand. SC reflects fluctuations in the eccrine sweat glands and is a relatively pure measure of cholinergic sympathetic activity (Darrow & Gullickson, 1970). Mean level (tonic) and the integral (phasic) of the skin conductance recording was quantified during each task as an index of arousal.

*Pulse Oximetry*

The pulse oximeter was attached to the tip of the middle finger on the left hand. Pulse oximetry measures oxygenation of the blood from the ratio of oxyhemoglobin to reduced hemoglobin in the blood flowing through the finger (Wagner & Ruskin, 2007). The mean level (%) of blood oxygen saturation ($SpO_2$) was quantified so as to index the degree to which the slow breathing and picture viewing tasks affected oxygenation of the blood.

*Electrogastrogram (EGG)*

Finally, EGG was measured by placing electrodes on the skin of the right and left side of the abdomen. EGG represents gastric contractions which are influenced by the autonomic nervous system (Muth et al., 1998). EGG provides a measure of autonomic activity from an organ rarely studied in cardiovascular research but has been related to self-reported arousal during emotion induction (Vianna & Tranel, 2006). The EGG was analyzed in the frequency domain (FFT) by examining normogastria frequency range: 2.5-3.75 cycles per minute (Muth et al., 1998).

## RESULTS

*Validity of Resonant Frequencies Calculated using Different Methods*

The validity of various methods of resonant frequency estimation was examined by Pearson correlations between the estimated resonant frequency from each method and the subject's height (the criterion). The paced picture presentation was the only method that significantly correlated with height ($r = -.25$, $p = .03$). Biofeedback ($r = -.07$, $p = .57$), paced breathing ($r = -.03$, $p = .79$), and paced picture breathing ($r = -.08$, $p = .62$), all failed to significantly correlate with height. No further statistical tests were conducted for the hypotheses regarding the validity of the various methods of estimating the resonant frequency as only one method was significantly related to the criterion.

*Physiological Effects of Different Methods of Resonant Stimulation*

*Paced Picture Presentation*

The effect of presenting pictures at 0.1 Hz relative to baseline was examined by running pairwise t-tests on all physiological variables (see Table 1 for means, standard deviations, t-values, and Cohen's D effect sizes). The paced picture presentation had a small but overall

significant effect on the respiratory system. Respiration rate increased nearly one breath per minute (Cohen's D = 0.24, p = 0.01), tidal volume decreased (Cohen's D = -0.38, p < 0.001), and minute ventilation decreased significantly (Cohen's D = -0.26, p = 0.002). These changes in respiration were also accompanied by a moderate decrease in $SpO_2$ (Cohen's D = -0.26, p = 0.010).

The paced picture presentation task did not have substantial effects on the cardiac system (see Table 1). Mean IBI, variation in IBI, RMSSD, pNN50, and low frequency power all evinced non-significant effects during the task (all p-values > 0.05). However, some measures of heart rate variability did show small significant effects. Respiratory sinus arrhythmia (RSA; peak-to-valley) decreased relative to baseline (Cohen's D = -0.14, p = 0.021), HF power decreased (Cohen's D = -0.16, p = 0.013), and power spectral density in the resonant Hz range (0.075 – 0.108 Hz) increased (Cohen's D = 0.23, p = 0.027).

Skin conductance was also affected by the paced picture presentation. The mean level of skin conductance decreased relative to baseline (Cohen's D = -0.16, p = 0.002) and the integral of the skin conductance recording also decreased (Cohen's D = -0.17, p = 0.001). The activity recorded by the electrogastrogram (EGG) decreased, however, the effect was small and non-significant (Cohen's D = -0.12, p = 0.108).

Repeated measures ANOVA was employed to test the interaction between gender and the physiological effects of the paced picture presentation task (see Table 2). There were significant gender differences on four of the cardiac indices (see Table 3 and Table 4 for gender specific means, SD, and effect sizes). Women (see Figure 1) displayed small and mostly non-significant increases on these cardiac indices during the paced picture presentation task (IBI, Cohen's D = 0.05, p = 0.40; RMSSD, Cohen's D = 0.10, p = .10; & HF power, Cohen's D = 0.01, p = 0.88).

However, the percentage of successive differences in IBI's greater than 50 msec (pNN50) did significantly increase roughly 2.5% in women (Cohen's D = 0.11, p = 0.05). All of these cardiac indices significantly decreased for men during the paced picture presentation task (IBI, Cohen's D = -0.12, p = 0.02; RMSSD, Cohen's D = -0.16, p = 0.01; pNN50, Cohen's D = -0.20, p = 0.01; HF power, Cohen's D = -0.33, p = 0.001).

*Paced Breathing*

The effect of the paced breathing at 0.1 Hz relative to baseline was examined by running pairwise t-tests on all physiological variables (see Table 5 for means, standard deviations, t-values, and Cohen's D effect sizes). The paced breathing task had an expected large and significant overall effect on the respiratory system. Respiration rate decreased on average about 10 breaths per minute (Cohen's D = -5.96, $p < 0.001$) and tidal volume increased (Cohen's D = 2.45, $p < 0.001$). Minute ventilation had a small and non-significant increase (Cohen's D = 0.06, p = 0.680). These changes in respiration were also accompanied by a strong increase in $SpO_2$ (Cohen's D = 1.26, $p < 0.001$).

The paced breathing task also had substantial effects on the cardiac system (see Table 5). The largest effects were increased heart rate variability in the resonant Hz range (0.075 – 0.108 Hz; Cohen's D = 2.64, $p < 0.001$), increased respiratory sinus arrhythmia (peak-to-valley; Cohen's D = 1.94, $p < 0.001$), and increased low frequency (0.05 – 0.15 Hz) heart rate variability (Cohen's D = 1.83, $p < 0.001$). The standard deviation of the IBI's also significantly increased (Cohen's D = 1.19, $p < 0.001$). Medium size increases were found for RMSSD (Cohen's D = 0.43, $p < 0.001$) and pNN50 (Cohen's D = 0.44, $p < 0.001$). Mean IBI (Cohen's D = 0.02, p = 0.731) and high frequency (0.15 – 0.40 Hz) heart rate variability (Cohen's D = -0.16, p = 0.127) did not significantly change.

Skin conductance was not affected by the paced breathing task. Neither the mean level of skin conductance (Cohen's D = -0.03, p = 0.496) nor the integral of the skin conductance recording (Cohen's D = -0.03, p = 0.451) significantly changed. The activity recorded by the electrogastrogram (EGG) did not significantly change either (Cohen's D = -0.12, p = 0.242).

Repeated measures ANOVA was employed to test the interaction between gender and the physiological effects of the paced breathing task (see Table 6). There were significant gender differences on one of the respiratory indices, two of the cardiac indices, and the electrogastrogram recording (see Table 7 and Table 8 for gender specific means, SD, and effect sizes). Both men (Cohen's D = 2.75, $p < 0.001$) and women (Cohen's D = 2.72, $p < 0.001$) significantly increased their tidal volume during the paced breathing task relative to baseline, however, the effect was somewhat stronger for men. The effect of paced breathing on the cardiac system was substantially stronger for women compared to men. Women had a greater increase in heart rate variability in the resonant Hz range (women, Cohen's D = 2.20, $p < 0.001$; men, Cohen's D = 1.54, $p < 0.001$) and the low frequency range (women, Cohen's D = 3.43, $p < 0.001$; men, Cohen's D = 2.14, $p < 0.001$). Conversely, only men had a significant change in the electrogastrogram recording during paced breathing (men, Cohen's D = -0.31, p = 0.01; women, Cohen's D = 0.19, p = 0.33).

Correlation analyses were conducted to examine the relationship between change in physiology during the paced breathing task and BMI. BMI was significantly correlated with change in minute ventilation (r = .36, $p = .003$) and change in $SpO_2$ (r = .29, $p = 0.018$). Subjects with higher BMI values tended to ventilate more air during the paced breathing task and exhibited large increases in $SpO_2$, whereas subjects with lower BMI values tended to ventilate

less air during the paced breathing task relative to baseline and exhibited moderate increases in $SpO_2$.

*Paced Picture Breathing*

The effect of the paced picture breathing at 0.1 Hz relative to baseline was examined by running pairwise t-tests on all physiological variables (see Table 9 for means, standard deviations, t-values, and Cohen's D effect sizes). The paced picture breathing task had an expected large and significant overall effect on the respiratory system. Respiration rate decreased on average about 10 breaths per minute (Cohen's D = -5.83, $p < 0.001$), tidal volume increased (Cohen's D = 2.59, $p < 0.001$), and minute ventilation decreased relative to baseline (Cohen's D = -0.47, $p < 0.001$). These changes in respiration were also accompanied by a strong increase in $SpO_2$ (Cohen's D = 1.11, $p < 0.001$).

The paced picture breathing task had substantial effects on the cardiac system as well (see Table 9). The largest effects were increased heart rate variability in the resonant Hz range (0.075 – 0.108 Hz; Cohen's D = 2.43, $p < 0.001$), increased respiratory sinus arrhythmia (peak-to-valley; Cohen's D = 2.20, $p < 0.001$), and increased low frequency (0.05 – 0.15 Hz) heart rate variability (Cohen's D = 1.75, $p < 0.001$). The standard deviation of the IBI's also significantly increased (Cohen's D = 1.25, $p < 0.001$). Medium size increases were found for RMSSD (Cohen's D = 0.51, $p < 0.001$) and pNN50 (Cohen's D = 0.52, $p < 0.001$). Mean IBI increased slightly but significantly (Cohen's D = 0.13, $p = 0.031$). High frequency (0.15 – 0.40 Hz) heart rate variability did not significantly change (Cohen's D = -0.09, $p = 0.035$).

Skin conductance was not affected by the paced picture breathing task. Neither the mean level of skin conductance (Cohen's D = -0.01, $p = 0.86$) nor the integral of the skin conductance

recording (Cohen's D = -0.01, p = 0.79) significantly changed. The activity recorded by the electrogastrogram (EGG) did not significantly change either (Cohen's D = -0.18, p = 0.19).

Repeated measures ANOVA was employed to test the interaction between gender and the physiological effects of the paced picture breathing task (see Table 10). There were significant gender differences on one of the respiratory indices and two of the cardiac indices (see Table 11 and Table 12 for gender specific means, SD, and effect sizes). Both men (Cohen's D = 2.65, $p < 0.001$) and women (Cohen's D = 3.17, $p < 0.001$) significantly increased their tidal volume during the paced picture breathing task relative to baseline, however, the effect was stronger for women. The effect of paced picture breathing on the cardiac system was substantially stronger for women compared to men. Women had a greater increase in heart rate variability in the resonant Hz range (women, Cohen's D = 3.11, $p < 0.001$; men, Cohen's D = 2.06, $p < 0.001$) and the low frequency range (women, Cohen's D = 2.33, $p < 0.001$; men, Cohen's D = 1.42 $p < 0.001$).

Correlation analyses were conducted to examine the relationship between change in physiology during the paced picture breathing task and body mass index (BMI). BMI was significantly correlated with change in minute ventilation ($r = .29$, $p = .02$), change in $SpO_2$ ($r = .36$, $p = 0.004$), change in low frequency ($r = -.37$, $p = 0.003$) and resonant frequency heart rate variability ($r = -.38$, $p = 0.002$). Subjects with higher BMI values tended to ventilate more or the same amount of air, exhibited large increases in $SpO_2$, and produced small increases in heart rate variability during the paced breathing task. Conversely, subjects with lower BMI values tended to ventilate less air, exhibited moderate increases in $SpO_2$, and produced large increases in heart rate variability during the paced breathing task.

*Biofeedback*

The effect of the biofeedback task relative to baseline was examined by running pairwise t-tests on all physiological variables (see Table 13 for means, standard deviations, t-values, and Cohen's D effect sizes). The biofeedback task had an expected large and significant overall effect on the respiratory system. Respiration rate decreased on average about 7 breaths per minute (Cohen's D = -2.80, $p < 0.001$), tidal volume increased (Cohen's D = 2.58, $p < 0.001$), and minute ventilation increased relative to baseline (Cohen's D = 0. 79, $p < 0.001$). These changes in respiration were also accompanied by a strong increase in $SpO_2$ (Cohen's D = 1.76, $p < 0.001$).

The biofeedback task had a considerable effect on the cardiac system as well (see Table 1000). The largest effects were increased respiratory sinus arrhythmia (peak-to-valley; Cohen's D = 1.89, $p < 0.001$), increased low frequency (0.05 – 0.15 Hz) heart rate variability (Cohen's D = 1.11, $p < 0.001$), and increased heart rate variability in the resonant Hz range (0.075 – 0.108 Hz; Cohen's D = 1.02, $p < 0.001$). The standard deviation of the IBI's also significantly increased (Cohen's D = 0.95, $p < 0.001$). Moderate size increases were found for RMSSD (Cohen's D = 0.43, $p < 0.001$) and pNN50 (Cohen's D = 0.34, $p < 0.001$), while mean IBI decreased significantly (Cohen's D = -0.24, $p < 0.001$). High frequency (0.15 – 0.40 Hz) heart rate variability did not significantly change (Cohen's D = 0.12, $p = 0.23$).

Skin conductance was significantly affected by the biofeedback task. Both the mean level of skin conductance (Cohen's D = 0.10, $p < 0.001$) and the integral of the skin conductance recording (Cohen's D = 0.10, $p < 0.001$) significantly increased. However, the activity recorded by the electrogastrogram (EGG) did not significantly change (Cohen's D = 0.16, $p = 0.26$).

Repeated measures ANOVA was employed to test the interaction between gender and the physiological effects of the biofeedback task (see Table 14). There were only significant gender differences on one of the respiratory indices (see Table 15 for gender specific means, SD, and effect sizes). Both men (Cohen's D = 2.88, $p < 0.001$) and women (Cohen's D = 2.77, $p < 0.001$) significantly increased their tidal volume during the biofeedback task relative to baseline, however, the effect was stronger for men.

*Effects of Emotion Induction on Paced Breathing*

*Effects of Emotion Induction on Self-Reported Emotion and Dyspnea*

The effect of the emotion induction during the paced picture breathing task relative to the regular paced breathing task was examined by running pairwise t-tests on all self-reported emotion and dyspnea measures (see Table 16 for means, standard deviations, and t-test results). As illustrated in Figure 2, emotion ratings differed significantly between the paced picture breathing and the paced breathing tasks in valence, $t(70) = 5.06$, $p < .001$), and in arousal, $t(70) = 6.46$, $p < .001$. The paced picture breathing task was reported as more arousing (mean = 3.62, SD = 1.78) and more pleasant (mean = 5.55, SD = 1.78) than the paced breathing task (arousal, mean = 2.06, SD = 1.43; pleasant, mean = 4.55, SD = 1.71). The paced picture breathing and the paced breathing tasks also significantly differed in terms of the intensity ($t(70) = 2.09$, $p = .04$) and the unpleasantness ($t(70) = 2.11$, $p = .04$) of dyspnea reported (see Figure 3). The level of dyspnea reported during the paced breathing task was more intense (mean = 3.34, SD = 2.44) and more unpleasant (mean = 3.70, SD = 2.88) than the level of dyspnea reported during the paced breathing task (mean = 2.85, SD = 2.18; mean = 3.08, SD = 2.39, respectively). The differences between the paced breathing and paced picture breathing tasks on the self-report measures did not significantly interact with gender (see Table 17).

*Effects of Emotion Induction on Physiology*

The physiological effects of the emotion induction during paced breathing was examined by conducting pairwise t-tests between all physiological variables collected during the paced breathing and paced picture breathing tasks (see Table 18 for means, standard deviations, t-values, and Cohen's D effect sizes). The emotion induction during the paced picture breathing task caused significantly less tidal volume compared to the paced breathing task (Cohen's D = -0.54, $p < 0.001$). The emotion induction also caused significantly larger IBI's (Cohen's D = 0.17, $p = 0.01$) and a significantly higher percentage of successive differences in IBI's greater than 50 msec (pNN50; Cohen's D = 0.15, $p < 0.03$).

Repeated measures ANOVA was also employed to test the interaction between gender and the physiological effects of the emotion induction (see Table 19). High frequency (0.15 – 0.40 Hz) heart rate variability was the only physiological variable which significantly interacted with gender (see Table 20 for gender specific means, SD, and effect sizes). Men exhibited significantly higher high frequency heart rate variability during the paced picture breathing task compared to the paced breathing task (Cohen's D = 0.32, $p = 0.01$). The level of high frequency heart rate variability for women during the paced picture breathing and paced breathing task were not significantly different (Cohen's D = -0.09, $p = 0.32$).

Correlation analyses were conducted to examine the relationship between BMI and physiological differences between the paced breathing and paced picture breathing tasks. BMI was significantly correlated with differences between the paced breathing and paced picture breathing tasks on measures of respiratory sinus arrhythmia (peak-to-valley; r = -.27, $p = .03$), respiration rate (r = .31, $p = 0.01$), and power in the normogastric range of the electrogastrogram (EGG; r = -.38, $p = 0.002$). Subjects with higher BMI values tended to have less RSA, increased

EGG activity, and higher respiration rates during the paced picture breathing relative to the paced breathing task. Subjects with lower BMI values tended to have increased RSA, less EGG activity, and lower respiration rates during the paced picture breathing relative to the paced breathing task.

*Relationships between Physiological and Self-Report Effects of Emotion Induction*

Physiological, emotion, and dyspnea difference scores were calculated by subtracting values obtained during the paced breathing task from the paced picture breathing task. These difference scores were then submitted to a correlation analysis to examine the relationship between physiological and self-report differences caused by the emotion induction (see Table 21). The significant correlation between overall pleasantness and overall arousal ($r = .38$, $p = .001$) indicates that the more pleasant the paced picture breathing task was rated compared to the paced breathing task, the more arousing the paced picture breathing task was rated as well. Similarly, the significant correlation between dyspnea intensity and dyspnea unpleasantness ($r = .78$, $p < .001$) indicates that as the dyspnea experienced during the paced breathing task was rated as more intense compared to the paced picture breathing task, the dyspnea experienced during the paced breathing task was also rated as more unpleasant. The greater unpleasantness of the dyspnea experienced and the lower overall self-reported pleasantness during paced breathing were also significantly correlated ($r = -.31$, $p = .008$).

Physiologically, the larger IBI's found during the paced picture breathing task were significantly related to lower intensity ($r = -.26$, $p = .035$) and unpleasantness ($r = -.32$, $p = .007$) levels of dyspnea reported during the paced picture breathing task. The larger inter-beat intervals were also significantly related to the lower levels of tidal volume ($r = -.31$, $p = .011$) and higher percentage of successive differences in IBI's greater than 50 msec (pNN50; $r = .50$, $p$

< .0017) found during the paced picture breathing task. Tidal volume and pNN50 differences between the paced breathing and paced picture breathing task were not related to any of the emotion or dyspnea self-report measures.

## DISCUSSION

### *Validity of Resonant Frequencies Calculated via Various Methods*

The first aim of the experiment was to examine the validity of various methods of determining a person's resonant frequency. The strength of the relationship between a person's height and resonant frequency was used as a criterion based on prior research (Vaschillo et al., 2006). However, the present study calls this practice into question. Neither the paced breathing nor biofeedback tasks yielded resonant frequencies which were significantly related to height. The paced picture presentation was the only method which produced resonant frequencies that correlated with height in the expected negative direction. Importantly, the difference between the picture presentation task and the other methods was slowed respiration.

Several subjects in the experiment appeared uncomfortable, irritated, or drowsy during the slow breathing tasks (visual observation by author). The paced picture presentation was always the first task completed, which afterwards many subjects seemed to gradually lose interest in the experiment. The motivational context of the present study is in sharp contrast to the prior study upon which the resonant frequency-height correlation showed the expected pattern (Vaschillo et al., 2006). As opposed to a mostly clinical sample, the present study was based upon college students who were meagerly motivated by two extra credit points. It is quite possible that these differences in motivation contributed error variance to the resonant frequency calculation during the respiratory methods and therefore diluted the small but expected

relationship. An experiment with a shorter duration and a greater explanation to the subjects regarding the importance of the research might alleviate these differences.

*Physiological Effects of Different Methods of Resonant Stimulation*

The second aim of the experiment was to describe the physiological profile of the various methods of resonant stimulation. The paced picture presentation is unique among these methods because it is the only task which did not include explicit breathing instructions. Therefore, the paced picture presentation will be considered separately.

*Paced Picture Presentation*

The paced picture presentation had considerable effects on the respiratory system. During the task, respiration rate increased, tidal volume decreased, subjects ventilated less air per minute, and $SpO_2$ decreased. Conversely, the cardiovascular system exhibited small effects. There was a small decrease in high frequency power and a moderate increase in spectral power at 0.1 Hz, the frequency at which the pictures were presented. Interestingly, skin conductance decreased during the picture presentation. This finding was somewhat surprising given that one would expect watching positively valenced pictures would elicit more sympathetic arousal relative to baseline. However, as the picture presentation was always the first task of the experiment, it is likely that anticipation and overall arousal decreased as the experiment progressed, and this decrease in arousal as a function of time is the explanation for the demonstrated decreased skin conductance relative to baseline.

Together, these findings represent an increase in cardiorespiratory arousal while engaged in a positive picture viewing task. As for stimulating resonance in the cardiovascular system, the task was largely unsuccessful. Large oscillations in heart rate were only observed in the narrow resonant frequency range (0.075 – 0.108 Hz) at which the pictures were presented. Low

frequency heart rate variability (0.04 – 0.15 Hz) was unaffected by the task, while high frequency heart rate variability decreased. Although the paced picture presentation was the most effective in determining a person's resonant frequency, visual stimulation via emotional pictures was not strong enough to induce profound cardiovascular resonance.

*Paced Picture Presentation and Gender*

Gender differences for the paced picture presentation were found in the cardiovascular system (see Figure 1). Men exhibited increased heart rate and decreased heart rate variability, while women displayed small and non-significant differences on these same measures. These findings are in line with the notion that men exhibit stronger physiological reactions to appetitive stimuli (Bradley et al., 2001). Elevated average heart rate in men might also indicate men had stronger orienting responses while viewing appetitive pictures (Sokolov, 1990). Prior research has shown that during a slideshow of pictures, stronger orienting responses (greater phasic bradycardia at picture onset) are related to higher levels of heart rate averaged across the entire task (Abercrombie, Chambers, Greischar, & Monticelli, 2008). A greater orienting response along with decreased heart rate variability may also be indicative of greater sustained attention and stronger encoding of the emotional pictures to memory (Abercrombie et al., 2008; Porges, 1992). Overall, men were more engaged with the pictures.

*Paced Breathing and Paced Picture Breathing*

The paced breathing and paced picture breathing tasks were both successful in decreasing respiration rate to six breaths per minute in the majority of subjects. However, it is important to note that five subjects were excluded because they failed to comply with the paced breathing protocol. While there were no significant differences on any self-report measure between the five excluded subjects and the rest of the sample, the excluded subjects tended to rate the paced

breathing tasks low on arousal and more unpleasant compared to the other subjects. Of particular relevance, the excluded subjects also reported higher levels of dyspnea on both the unpleasantness and intensity dimension. Although these differences were not significant, they are likely related to the lack of adherence to the paced breathing protocol by the excluded subjects. Slow paced breathing requires a certain amount of physical and mental effort and it is to be expected that a small number of novice individuals will initially fail to comply with difficult breathing protocols.

The decrease in respiration rate during both paced respiration tasks was accompanied by an increase in tidal volume, an increase in heart rate variability, and an increase in $SpO_2$. Although minute ventilation (the amount of air ventilated per minute) either decreased moderately or remained relatively unchanged, $SpO_2$ still increased substantially during paced respiration. The increase in $SpO_2$ is likely related to the increase in tidal volume and a resulting decrease in dead space (the portion of inhaled air that does not come into contact with pulmonary capillaries). Because the same amount of air entered the lungs in a fewer number of breaths, a larger portion of oxygen was allowed to perfuse into the pulmonary capillaries. In addition, heightened heart rate variability likely increased blood flow to the pulmonary capillaries by increasing the number of heart beats during inspiration, which would allow more blood to be oxygenated and further increase $SpO_2$. Therefore, the resulting physiological pattern of paced breathing at 0.1 Hz is consistent with the theory that slow paced breathing increases pulmonary gas exchange efficiency (Giardino et al., 2003; Hayano et al., 1996).

*Paced Breathing, Paced Picture Breathing, and Gender*

Although the paced breathing tasks induced relatively the same physiological profile in male and female subjects, gender differences were present. Women consistently demonstrated

greater increases in heart rate variability in the low (0.04 – 0.15 Hz) and resonant frequency (0.075 – 0.108 Hz) range. This gender difference is evidently a result of lower baseline values on these measures in women, combined with similar task values between males and females.

A more interesting, and unfortunately puzzling, gender difference was found in the gastric system during the paced breathing, but not the paced picture breathing task. Men displayed a moderate decrease in power in the normal gastric frequency (0.041 – 0.058 Hz), while women showed a non-significant increase. As the power in normal frequency range of the electrogastrogram is indicative of gastric motility and parasympathetic activity, these findings indicate that men exhibited a decrease in stomach motility, while women displayed no change. Unfortunately, there are no studies which have examined the effects of slow paced breathing on gastric motility, let alone reports of gender differences. Interpretation of these findings must await further research.

*Biofeedback*

The biofeedback task differed from the paced breathing tasks in several ways. During the biofeedback task, subjects were instructed to breathe in phase with their heart rate so as to maximize oscillations in their heart rate, rather than follow a pacing stimulus per se. While these instructions were followed in the beginning of the task, many subjects gradually increased their respiration rate toward a more natural pace. This tendency was demonstrated in the mean respiration rate for the biofeedback task, which was well above the expected average of six breaths per minute. Furthermore, interpretation of the physiological effects of the biofeedback task proved difficult due to the severe between and within subject variability in respiration rate during the task. These findings demonstrate the need for a pacing stimulus for novice slow breathers until they become more acclimated to this style of breathing.

*Emotion Induction Effects on Paced Breathing*

The emotion induction was effective in attenuating ill perceptions of paced breathing at 0.1 Hz. Paced breathing alone was viewed as unpleasant and boring. The emotion induction successfully changed the perceived valence of the task from unpleasant to pleasant and diminished the boring, low-arousal nature of slow paced breathing. The ability of positive emotion to diminish breathing discomfort and even pain is well established (von Leupoldt et al., 2006; Rainville, Bao, & Chretien, 2005). Therefore, one of the central hypotheses of the present experiment was that the emotion induction would attenuate perceptions of dyspnea during the paced breathing task. This hypothesis was confirmed as dyspnea was significantly diminished during paced breathing with the emotion induction compared to paced breathing without.

The effects of the emotion induction on dyspnea during paced breathing do differ in some ways from prior reports. While previous research has only demonstrated an attenuation of the unpleasantness or affective dimension of dyspnea, in the current experiment the intensity or sensory dimension of dyspnea was also diminished by the emotion induction. This discrepancy is most likely explained by physiological differences during paced breathing with the emotion induction, namely less tidal volume and lower heart rate. Greater expansion of the lungs and sensations of a faster heart beat are likely contributors to the differences in the sensory component of dyspnea. These findings are in contrast to prior research in which no physiological differences were observed because a resistive load breathing circuit was used to induce a constant strain on the respiratory muscles across the experimental and control conditions (von Leupoldt et al., 2006).

Although the emotion induction appears to have had beneficial effects on the paced breathing task, this interpretation is not without caveats. The lack of experimental control over

the source of dyspnea must be appreciated. Also, it may be that the perceived and physiological differences between the paced breathing tasks are attributable to a factor other than the emotion induction. Such a difference may be the pacing stimulus itself, which differed between the two paced breathing conditions. In the paced picture breathing task, subjects inhaled and exhaled as pictures turned off and on, as opposed to the regular paced breathing task in which subjects breathed in sync with a bar moving up and down. It is possible that the vertically moving bar induced deeper breaths and greater cardiac acceleration, in addition to overall discomfort and unpleasant perceptions. This speculation can only be addressed by an attempt to replicate the present findings with a revised procedure. However, there is no research supporting the notion that different pacing stimuli significantly affect physiological and psychological parameters during paced breathing. There is evidence, however, that an emotion induction can diminish dyspnea or pain, and that viewing pleasant pictures is one context in which this will occur.

*Interaction between Gender and Emotion Induction Effects on Paced Breathing*

The emotion induction had similar effects on paced breathing for both male and female subjects; both rated paced breathing as more pleasant, more arousing, and reported lower perceptions of dyspnea when paced breathing was combined with the emotion induction. However, men exhibited higher levels of HF heart rate variability during paced breathing with the emotion induction, relative to paced breathing alone. Women displayed no significant differences on this measure. This finding is possibly related to the difference between men and women on HF heart rate variability found during the paced picture presentation task, where men showed significant decreases on HF heart rate variability while women did not. Perhaps the increase in HF heart rate variability represents an increase in parasympathetic tone, indicative of

a more acquiescent physiological profile in men when paced breathing was combined with appealing pictures.

## CONCLUSION

The present study demonstrates a failure to accurately estimate the resonant frequency using respiratory methods. However, all respiratory methods produced profound effects in the cardiovascular system, with some differences in the magnitude of effect. Although prior research has focused on developing protocols that focus on resonant frequency estimation, it is likely that simply breathing at six breaths per minute would induce large oscillations in heart rate, blood pressure, and exercise the baroreflex. It is quite possible that the long term effects of breathing at six breaths per minute are indistinguishable from breathing at one's putative resonant frequency, which has been show to fluctuate over time. The present study did successfully demonstrate the utility of an emotion induction during slow paced breathing. Dyspnea levels decreased and affect improved. This effect may be analogous to listening to music while exercising. Further research should test for differences between neutral and positive emotional distractions. The present study also supports the notion that slow breathing improves pulmonary gas exchange efficiency, in addition to strengthening the baroreflex, by increasing heart rate variability. Further research should examine how psychological and physiological correlates of low levels heart rate variability are related to inefficient pulmonary gas exchange.

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# APPENDIX A

## FIGURES

Figure 1

Cardiac differences between men and women during a paced picture presentation

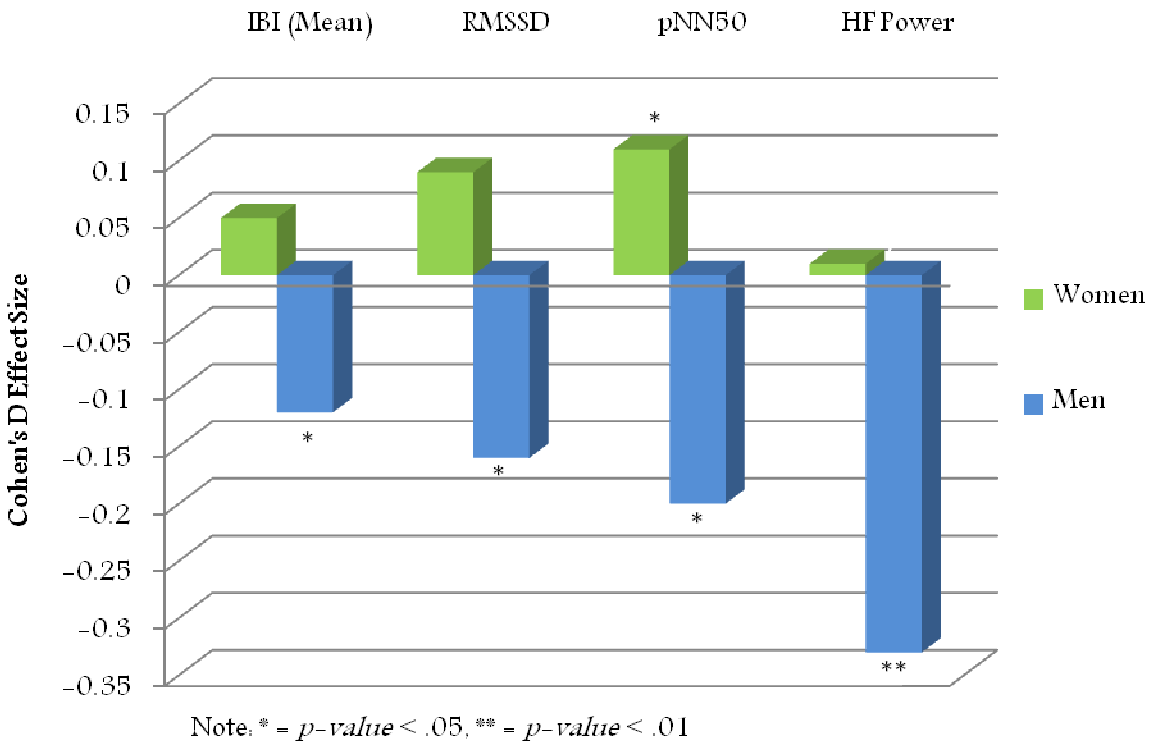


Figure 2

SAM ratings of valence and arousal during paced breathing and picture paced breathing (1 = unpleasant / low arousal; 5 = neutral; 9 = high pleasant / pleasant).

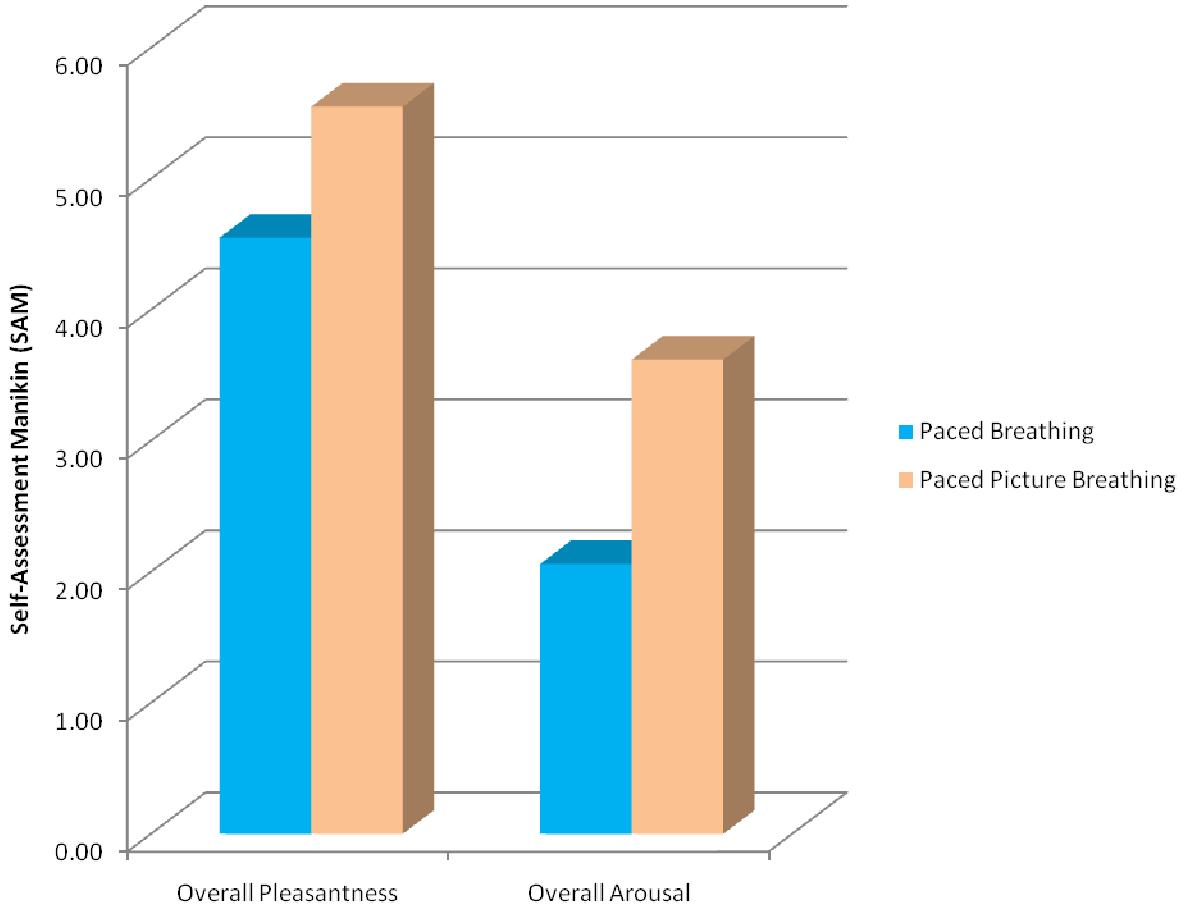
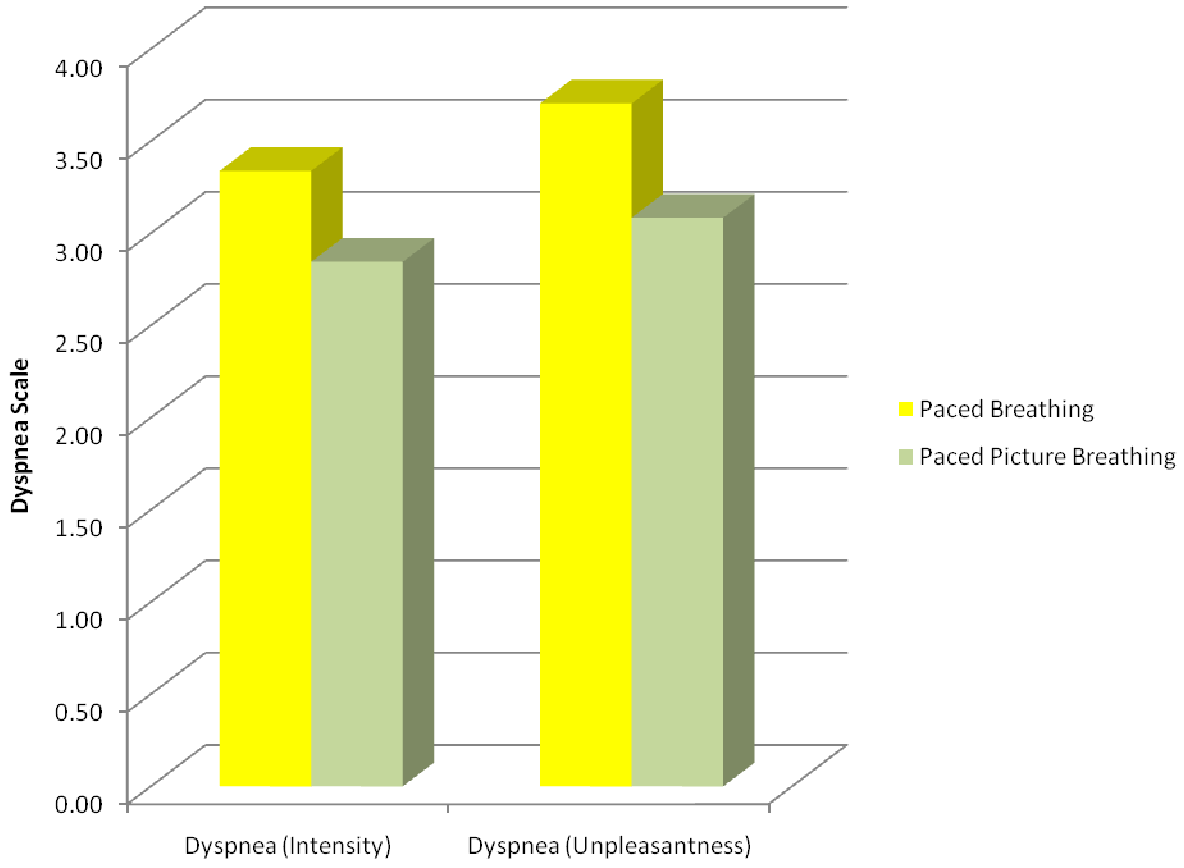


Figure 3

Intensity & unpleasantness of dyspnea during paced breathing & picture paced breathing (0 = not noticeable / not unpleasant; 10 = maximal imaginable intensity / maximal imaginable unpleasantness).



# APPENDIX B

## TABLES

Table 1

*Picture Presentation: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| Respiration Rate | 15.38 | 2.97 | 16.10 | 3.12 | 2.61 | 68 | 0.011 | 0.24 |
| Tidal Volume | 0.33 | 0.10 | 0.29 | 0.09 | -4.19 | 68 | 0.000 | -0.38 |
| Minute Ventilation | 4.84 | 1.37 | 4.49 | 1.36 | -3.30 | 68 | 0.002 | -0.26 |
| RSA | 86.96 | 69.02 | 77.14 | 71.80 | -2.37 | 67 | 0.021 | -0.14 |
| $SpO_2$ | 97.25 | 0.49 | 97.12 | 0.48 | -2.67 | 67 | 0.010 | -0.26 |
| IBI (Mean) | 853.15 | 126.29 | 847.23 | 127.62 | -1.28 | 68 | 0.205 | -0.05 |
| IBI (SD) | 54.41 | 26.21 | 52.38 | 25.34 | -1.45 | 68 | 0.151 | -0.08 |
| RMSSD | 53.25 | 32.55 | 51.85 | 34.27 | -0.98 | 68 | 0.332 | -0.04 |
| pNN50 | 27.94 | 22.28 | 27.23 | 23.04 | -0.65 | 68 | 0.520 | -0.03 |
| LF power | 6.79 | 1.05 | 6.85 | 0.95 | 0.68 | 68 | 0.500 | 0.06 |
| HF power | 6.92 | 1.29 | 6.71 | 1.29 | -2.56 | 68 | 0.013 | -0.16 |
| Resonant Hz PSD | 9.36 | 1.11 | 9.60 | 1.00 | 2.26 | 68 | 0.027 | 0.23 |
| GSR Left Mean | 0.75 | 0.04 | 0.74 | 0.05 | -3.16 | 68 | 0.002 | -0.16 |
| GSR Left Integral | 4.91 | 0.08 | 4.89 | 0.09 | -3.34 | 68 | 0.001 | -0.17 |
| EGG power | 5.40 | 0.94 | 5.29 | 0.89 | -1.63 | 68 | 0.108 | -0.12 |

Table 2

*Picture Presentation: Interaction between Gender and Picture Presentation Task Effects*

| Physiological Measure | df | F | Significance | Partial Eta Squared |
|---|---|---|---|---|
| | | | | |
| Respiration Rate | 1 | 0.864 | 0.356 | 0.014 |
| Tidal Volume | 1 | 0.090 | 0.765 | 0.001 |
| Minute Ventilation | 1 | 0.779 | 0.381 | 0.012 |
| RSA | 1 | 0.892 | 0.349 | 0.014 |
| $SpO_2$ | 1 | 0.009 | 0.926 | 0.000 |
| IBI (Mean) | 1 | 9.055 | 0.004 | 0.126 |
| IBI (SD) | 1 | 2.791 | 0.100 | 0.042 |
| RMSSD | 1 | 12.073 | 0.001 | 0.161 |
| pNN50 | 1 | 16.756 | 0.000 | 0.210 |
| LF Power | 1 | 0.042 | 0.839 | 0.001 |
| HF Power | 1 | 12.671 | 0.001 | 0.167 |
| Resonant Hz PSD | 1 | 0.028 | 0.869 | 0.000 |
| GSR Left Mean | 1 | 0.707 | 0.404 | 0.011 |
| GSR Left Integral | 1 | 0.656 | 0.421 | 0.010 |
| EGG | 1 | 0.070 | 0.793 | 0.001 |

Table 3

*Picture Presentation (Women): Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| IBI (Mean) | 838.58 | 108.05 | 843.45 | 107.87 | 0.85 | 34 | 0.40 | 0.05 |
| RMSSD | 49.12 | 29.76 | 51.87 | 31.12 | 1.67 | 34 | 0.10 | 0.09 |
| pNN50 | 26.22 | 23.47 | 28.94 | 24.26 | 2.06 | 34 | 0.05 | 0.11 |
| HF Power | 6.78 | 1.31 | 6.80 | 1.25 | 0.15 | 34 | 0.88 | 0.01 |

Table 4

*Picture Presentation (Men): Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Physiological Measure* | *Mean* | *SD* | *Mean* | *SD* | *t-value* | *df* | *p-value* | *Cohen's D* |
| | | | | | | | | |
| IBI (Mean) | 868.14 | 142.76 | 851.13 | 146.77 | -2.48 | 33 | 0.02 | -0.12 |
| RMSSD | 57.49 | 35.12 | 51.84 | 37.72 | -2.65 | 33 | 0.01 | -0.16 |
| pNN50 | 29.71 | 21.19 | 25.48 | 21.93 | -2.73 | 33 | 0.01 | -0.20 |
| HF Power | 7.06 | 1.28 | 6.62 | 1.34 | -3.68 | 33 | 0.00 | -0.33 |

Table 5

*Paced Breathing: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| Respiration Rate | 16.11 | 2.39 | 6.02 | 0.06 | -34.44 | 66 | 0.000 | -5.96 |
| Tidal Volume | 0.29 | 0.10 | 0.77 | 0.26 | 15.73 | 66 | 0.000 | 2.45 |
| Minute Ventilation | 4.58 | 1.33 | 4.66 | 1.57 | 0.41 | 66 | 0.680 | 0.06 |
| RSA | 64.76 | 47.52 | 301.04 | 165.70 | 12.28 | 66 | 0.000 | 1.94 |
| $SpO_2$ | 96.84 | 0.71 | 97.67 | 0.59 | 8.90 | 66 | 0.000 | 1.26 |
| IBI (Mean) | 857.26 | 129.21 | 860.05 | 114.21 | 0.35 | 66 | 0.731 | 0.02 |
| IBI (SD) | 57.36 | 28.34 | 98.95 | 40.56 | 12.61 | 67 | 0.000 | 1.19 |
| RMSSD | 52.49 | 35.91 | 67.72 | 34.88 | 5.23 | 66 | 0.000 | 0.43 |
| pNN50 | 23.36 | 20.07 | 31.67 | 17.54 | 4.71 | 66 | 0.000 | 0.44 |
| LF power | 7.16 | 1.04 | 8.88 | 0.83 | 18.61 | 66 | 0.000 | 1.83 |
| HF power | 6.68 | 1.27 | 6.49 | 1.11 | -1.54 | 66 | 0.127 | -0.16 |
| Resonant Hz PSD | 9.95 | 1.16 | 12.86 | 1.04 | 20.66 | 66 | 0.000 | 2.64 |
| GSR Left Mean | 0.76 | 0.05 | 0.75 | 0.05 | -0.69 | 66 | 0.496 | -0.03 |
| GSR Left Integral | 4.91 | 0.09 | 4.91 | 0.09 | -0.76 | 66 | 0.451 | -0.03 |
| EGG power | 5.42 | 0.81 | 5.31 | 0.92 | -1.18 | 66 | 0.242 | -0.12 |

Table 6

*Paced Breathing: Interaction between Gender and Paced Breathing Task Effects*

| Physiological Measure | df | F | Significance | Partial Eta Squared |
|---|---|---|---|---|
| | | | | |
| Respiration Rate | 1 | 0.228 | 0.635 | 0.004 |
| Tidal Volume | 1 | 6.947 | 0.011 | 0.099 |
| Minute Volume | 1 | 0.351 | 0.556 | 0.006 |
| RSA | 1 | 0.215 | 0.644 | 0.003 |
| SpO2 | 1 | 0.540 | 0.465 | 0.009 |
| IBI (Mean) | 1 | 0.934 | 0.337 | 0.015 |
| IBI (SD) | 1 | 1.848 | 0.179 | 0.028 |
| RMSSD | 1 | 0.034 | 0.854 | 0.001 |
| pNN50 | 1 | 1.193 | 0.279 | 0.019 |
| LF power | 1 | 10.681 | 0.002 | 0.145 |
| HF power | 1 | 0.793 | 0.377 | 0.012 |
| Resonant Hz PSD | 1 | 13.094 | 0.001 | 0.172 |
| GSR Left Mean | 1 | 0.264 | 0.609 | 0.004 |
| GSR Left Integral | 1 | 0.314 | 0.578 | 0.005 |
| EGG | 1 | 5.985 | 0.017 | 0.087 |

Table 7

*Paced Breathing (Women): Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| Tidal Volume | 0.33 | 0.09 | 0.90 | 0.28 | 11.09 | 30 | 0.00 | 2.72 |
| LF power | 6.94 | 0.96 | 8.95 | 0.86 | 16.69 | 30 | 0.00 | 2.20 |
| Resonant Hz PSD | 9.64 | 1.01 | 13.02 | 0.95 | 18.73 | 30 | 0.00 | 3.43 |
| EGG | 5.30 | 0.62 | 5.43 | 0.76 | 1.00 | 30 | 0.33 | 0.19 |

Table 8

*Paced Breathing (Men): Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| Tidal Volume | 0.25 | 0.09 | 0.67 | 0.19 | 12.35 | 35 | 0.00 | 2.75 |
| LF power | 7.36 | 1.08 | 8.82 | 0.80 | 11.91 | 35 | 0.00 | 1.54 |
| Resonant Hz PSD | 10.22 | 1.22 | 12.72 | 1.11 | 13.33 | 35 | 0.00 | 2.14 |
| EGG | 5.51 | 0.95 | 5.20 | 1.04 | -2.63 | 35 | 0.01 | -0.31 |

Table 9

*Paced Picture Breathing: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| Respiration Rate | 16.02 | 2.43 | 6.01 | 0.05 | -33.06 | 63 | 0.00 | -5.83 |
| Tidal Volume | 0.28 | 0.08 | 0.65 | 0.19 | 16.46 | 63 | 0.00 | 2.59 |
| Minute Ventilation | 4.45 | 1.21 | 3.90 | 1.11 | -3.40 | 63 | 0.00 | -0.47 |
| RSA | 63.25 | 46.93 | 290.39 | 138.17 | 14.67 | 63 | 0.00 | 2.20 |
| SpO2 | 96.82 | 0.84 | 97.62 | 0.57 | 7.47 | 64 | 0.00 | 1.11 |
| IBI (Mean) | 857.69 | 120.37 | 873.42 | 119.31 | 2.20 | 64 | 0.03 | 0.13 |
| IBI (SD) | 59.01 | 28.32 | 102.59 | 40.37 | 12.49 | 64 | 0.00 | 1.25 |
| RMSSD | 52.33 | 33.78 | 69.89 | 35.31 | 6.53 | 64 | 0.00 | 0.51 |
| pNN50 | 24.72 | 19.08 | 34.44 | 18.02 | 6.07 | 64 | 0.00 | 0.52 |
| LF power | 7.25 | 0.96 | 8.88 | 0.89 | 14.57 | 64 | 0.00 | 1.75 |
| HF power | 6.73 | 1.21 | 6.62 | 1.02 | -0.94 | 64 | 0.35 | -0.09 |
| Resonant Hz PSD | 10.00 | 1.06 | 12.77 | 1.21 | 16.15 | 64 | 0.00 | 2.43 |
| GSR Left Mean | 0.76 | 0.05 | 0.76 | 0.05 | -0.17 | 67 | 0.86 | -0.01 |
| GSR Left Integral | 4.91 | 0.09 | 4.91 | 0.10 | -0.26 | 67 | 0.79 | -0.01 |
| EGG power | 5.52 | 0.69 | 5.41 | 0.60 | -1.34 | 65 | 0.19 | -0.18 |

Table 10

*Interaction between Gender and Paced Picture Breathing Task Effects*

| Physiological Measure | df | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|
| Respiration Rate | 1 | 1.13 | 0.29 | 0.02 |
| Tidal Volume | 1 | 6.73 | 0.01 | 0.10 |
| Minute Volume | 1 | 0.36 | 0.55 | 0.01 |
| RSA | 1 | 0.04 | 0.84 | 0.00 |
| SpO2 | 1 | 2.38 | 0.13 | 0.04 |
| IBI (Mean) | 1 | 0.00 | 0.96 | 0.00 |
| IBI (SD) | 1 | 2.32 | 0.13 | 0.04 |
| RMSSD | 1 | 0.00 | 0.96 | 0.00 |
| pNN50 | 1 | 1.28 | 0.26 | 0.02 |
| LF power | 1 | 12.86 | 0.00 | 0.18 |
| HF power | 1 | 1.35 | 0.25 | 0.02 |
| Resonant Hz PSD | 1 | 14.01 | 0.00 | 0.19 |
| GSR Left Mean | 1 | 1.39 | 0.24 | 0.02 |
| GSR Left Integral | 1 | 1.40 | 0.24 | 0.02 |
| EGG | 1 | 0.05 | 0.83 | 0.00 |

Table 11

*Paced Picture Breathing (Women): Means, Standard Deviations, Pairwise T-tests & Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| Tidal Volume | 0.32 | 0.08 | 0.74 | 0.17 | 13.11 | 29 | 0.00 | 3.17 |
| LF power | 6.81 | 0.87 | 8.86 | 0.89 | 12.85 | 29 | 0.00 | 2.33 |
| Resonant Hz PSD | 9.45 | 0.98 | 12.85 | 1.19 | 13.99 | 29 | 0.00 | 3.11 |

Table 12

*Paced Picture Breathing (Men): Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| Tidal Volume | 0.25 | 0.06 | 0.57 | 0.16 | 11.04 | 33 | 0.00 | 2.65 |
| LF power | 7.63 | 0.89 | 8.91 | 0.91 | 9.69 | 34 | 0.00 | 1.42 |
| Resonant Hz PSD | 10.48 | 0.88 | 12.69 | 1.24 | 11.06 | 34 | 0.00 | 2.06 |

Table 13

*Biofeedback: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| Respiration Rate | 15.73 | 2.65 | 8.32 | 2.64 | -16.90 | 65 | 0.00 | -2.80 |
| Tidal Volume | 0.30 | 0.09 | 0.79 | 0.25 | 17.87 | 65 | 0.00 | 2.58 |
| Minute Ventilation | 4.64 | 1.55 | 6.58 | 3.10 | 5.83 | 65 | 0.00 | 0.79 |
| RSA | 63.55 | 40.78 | 232.08 | 119.02 | 12.01 | 65 | 0.00 | 1.89 |
| SpO2 | 96.95 | 0.66 | 98.02 | 0.55 | 12.98 | 67 | 0.00 | 1.76 |
| IBI (Mean) | 861.17 | 127.01 | 830.83 | 121.58 | -4.29 | 67 | 0.00 | -0.24 |
| IBI (SD) | 57.24 | 25.28 | 87.14 | 36.72 | 9.49 | 67 | 0.00 | 0.95 |
| RMSSD | 51.15 | 30.38 | 65.13 | 34.26 | 6.10 | 67 | 0.00 | 0.43 |
| pNN50 | 24.97 | 19.48 | 31.27 | 18.01 | 3.76 | 67 | 0.00 | 0.34 |
| LF power | 7.21 | 0.98 | 8.34 | 1.07 | 8.85 | 67 | 0.00 | 1.11 |
| HF power | 6.71 | 1.09 | 6.84 | 1.20 | 1.22 | 67 | 0.23 | 0.12 |
| Resonant Hz PSD | 9.92 | 1.07 | 11.36 | 1.71 | 6.97 | 67 | 0.00 | 1.02 |
| GSR Left Mean | 0.75 | 0.05 | 0.76 | 0.05 | 2.93 | 65 | 0.00 | 0.10 |
| GSR Left Integral | 4.91 | 0.09 | 4.92 | 0.10 | 2.94 | 65 | 0.00 | 0.10 |
| EGG power | 5.53 | 0.69 | 5.64 | 0.69 | 1.14 | 67 | 0.26 | 0.16 |

Table 14

*Biofeedback: Interaction between Gender and Paced Picture Breathing Task Effects*

| Physiological Measure | df | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|
| Respiration Rate | 1 | 0.04 | 0.84 | 0.00 |
| Tidal Volume | 1 | 5.63 | 0.02 | 0.08 |
| Minute Volume | 1 | 1.25 | 0.27 | 0.02 |
| RSA | 1 | 0.78 | 0.38 | 0.01 |
| SpO2 | 1 | 3.19 | 0.08 | 0.05 |
| IBI (Mean) | 1 | 0.09 | 0.76 | 0.00 |
| IBI (SD) | 1 | 0.00 | 0.95 | 0.00 |
| RMSSD | 1 | 0.03 | 0.87 | 0.00 |
| pNN50 | 1 | 0.01 | 0.93 | 0.00 |
| LF power | 1 | 0.32 | 0.57 | 0.01 |
| HF power | 1 | 0.11 | 0.74 | 0.00 |
| Resonant Hz PSD | 1 | 0.51 | 0.48 | 0.01 |
| GSR Left Mean | 1 | 0.41 | 0.52 | 0.01 |
| GSR Left Integral | 1 | 0.32 | 0.57 | 0.01 |
| EGG | 1 | 2.13 | 0.15 | 0.03 |

Table 15

*Biofeedback and Gender: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Baseline | | Task | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| Tidal Volume (Women) | 0.34 | 0.09 | 0.90 | 0.27 | 12.67 | 30 | 0.00 | 2.77 |
| Tidal Volume (Men) | 0.26 | 0.08 | 0.70 | 0.20 | 13.60 | 34 | 0.00 | 2.88 |

Table 16

*Emotion and Dyspnea: Means, Standard Deviations, and Pairwise T-tests*

| | Paced Breathing | | Paced Picture Breathing | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | t-value | df | Sig. | Cohen's D |
| Overall Pleasantness | 4.55 | 1.71 | 5.55 | 1.48 | 5.06 | 70 | 0.00 | 0.62 |
| Overall Arousal | 2.06 | 1.43 | 3.62 | 1.78 | 6.46 | 70 | 0.00 | 0.97 |
| Dyspnea - Intensity | 3.34 | 2.44 | 2.85 | 2.18 | 2.09 | 70 | 0.04 | 0.21 |
| Dyspnea - Unpleasantness | 3.70 | 2.88 | 3.08 | 2.39 | 2.11 | 70 | 0.04 | 0.23 |

Table 17

*Emotion and Dyspnea: Interaction between Task Differences and Gender*

| Self-Report Measure | *df* | F | Significance | Partial Eta Squared |
|---|---|---|---|---|
| | | | | |
| Overall Pleasantness | 1.00 | 0.08 | 0.78 | 0.00 |
| Overall Arousal | 1.00 | 0.44 | 0.51 | 0.01 |
| Dyspnea (Intensity) | 1.00 | 0.02 | 0.88 | 0.00 |
| Dyspnea (Unpleasantness) | 1.00 | 0.87 | 0.36 | 0.01 |

Table 18

*Physiological Effects of Emotion Induction: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | **Paced Picture Breathing** | | **Paced Breathing** | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | *df* | Sig. | Cohen's D |
| Respiration Rate | 6.02 | 0.05 | 6.01 | 0.06 | 0.30 | 66 | 0.77 | 0.05 |
| Tidal Volume | 0.65 | 0.19 | 0.77 | 0.25 | -5.21 | 66 | 0.00 | -0.54 |
| RSA | 290.02 | 136.65 | 296.11 | 150.76 | -0.47 | 66 | 0.64 | -0.04 |
| SpO2 | 97.58 | 0.61 | 97.71 | 0.59 | -1.69 | 66 | 0.10 | -0.21 |
| IBI (Mean) | 875.02 | 118.66 | 855.74 | 108.69 | 2.78 | 66 | 0.01 | 0.17 |
| IBI (SD) | 102.91 | 40.33 | 99.70 | 40.55 | 1.14 | 67 | 0.26 | 0.08 |
| RMSSD | 70.34 | 35.61 | 67.99 | 35.13 | 0.98 | 66 | 0.33 | 0.07 |
| pNN50 | 34.59 | 17.83 | 31.96 | 17.62 | 2.20 | 66 | 0.03 | 0.15 |
| LF power | 8.90 | 0.89 | 8.90 | 0.83 | 0.04 | 66 | 0.97 | 0.00 |
| HF power | 6.61 | 1.05 | 6.48 | 1.11 | 1.30 | 66 | 0.20 | 0.11 |
| Resonant Hz PSD | 12.82 | 1.20 | 12.90 | 1.03 | -0.89 | 66 | 0.38 | -0.07 |
| GSR Left Mean | 0.76 | 0.05 | 0.75 | 0.05 | 0.89 | 68 | 0.38 | 0.04 |
| GSR Left Integral | 4.91 | 0.10 | 4.91 | 0.09 | 0.89 | 68 | 0.37 | 0.04 |
| EGG power | 5.42 | 0.60 | 5.36 | 0.62 | 0.77 | 66 | 0.44 | 0.10 |

Table 19

*Interactions between Gender and Physiological Effects of Emotion Induction*

| Physiological Measure | df | F | Significance | Partial Eta Squared |
|---|---|---|---|---|
| | | | | |
| Respiration Rate | 1 | 0.43 | 0.51 | 0.01 |
| Tidal Volume | 1 | 0.13 | 0.72 | 0.00 |
| RSA | 1 | 0.21 | 0.65 | 0.00 |
| SpO2 | 1 | 0.30 | 0.58 | 0.00 |
| IBI (Mean) | 1 | 3.11 | 0.08 | 0.05 |
| IBI (SD) | 1 | 0.92 | 0.34 | 0.01 |
| RMSSD | 1 | 2.14 | 0.15 | 0.03 |
| pNN50 | 1 | 2.55 | 0.12 | 0.04 |
| LF Power | 1 | 0.64 | 0.43 | 0.01 |
| HF Power | 1 | 4.14 | 0.05 | 0.06 |
| Resonant Hz PSD | 1 | 0.00 | 0.96 | 0.00 |
| GSR Left Mean | 1 | 0.37 | 0.54 | 0.01 |
| GSR Left Integral | 1 | 0.39 | 0.54 | 0.01 |
| EGG | 1 | 0.41 | 0.53 | 0.01 |

Table 20

*Emotion Induction and Gender: Means, Standard Deviations, Pairwise T-tests, and Cohen's D*

| | Paced Picture Breathing | | Paced Breathing | | | | | |
|---|---|---|---|---|---|---|---|---|
| Physiological Measure | Mean | SD | Mean | SD | t-value | df | p-value | Cohen's D |
| | | | | | | | | |
| HF power (Women) | 6.45 | 1.12 | 6.55 | 1.20 | -0.76 | 31 | 0.46 | -0.09 |
| HF power (Men) | 6.75 | 0.98 | 6.43 | 1.03 | 2.66 | 34 | 0.01 | 0.32 |

Table 21

*Effects of Emotion Induction: Correlations between Physiological and Self-Report*

| Measure | Overall Pleasantness | Overall Arousal | Dyspnea (Intensity) | Dyspnea (Unpleasantness) | Tidal Volume | IBI |
|---|---|---|---|---|---|---|
| Overall Arousal | .38** | | | | | |
| Dyspnea (Intensity) | -.10 | .02 | | | | |
| Dyspnea (Unpleasantness) | -.31* | -.16 | .78** | | | |
| Tidal Volume | -.07 | -.02 | -.03 | .01 | | |
| IBI | .11 | .11 | -.26* | -.32** | -.31* | |
| pNN50 | .09 | .30* | -.21 | -.30* | .17 | .50** |

# Appendix C

## Dyspnea Questionnaire

Rate the intensity of breathing discomfort you experienced during the task, with 0 meaning the breathing discomfort was not noticeably intense and 10 meaning the breathing discomfort was the maximal imaginable intensity.

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Not noticeably intense | | | | | | | | | | Maximal imaginable intensity |

Rate the unpleasantness of breathing discomfort you experienced during the task, with 0 meaning the breathing discomfort was not unpleasant and 10 meaning the breathing discomfort was unpleasant.

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Not unpleasant | | | | | | | | | | Unpleasant |