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Relationship Between Dysfunctional Breathing Patterns and Ability to Achieve Target Heart Rate Variability With Features of "Coherence" During Biofeedback

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Abstract: Heart rate variability (HRV) biofeedback is a self-regulation strategy used to improve conditions including asthma, stress, hypertension, and chronic obstructive pulmonary disease. Respiratory muscle function affects hemodynamic influences on respiratory sinus arrhythmia (RSA), and HRV and HRV-biofeedback protocols often include slow abdominal breathing to achieve physiologically optimal patterns of HRV with power spectral distribution concentrated around the 0.1-Hz frequency and large amplitude. It is likely that optimal balanced breathing patterns and ability to entrain heart rhythms to breathing reflect physiological efficiency and resilience and that individuals with dysfunctional breathing patterns may have difficulty voluntarily modulating HRV and RSA. The relationship between breathing movement patterns and HRV, however, has not been investigated. This study examines how individuals' habitual breathing patterns correspond with their ability to optimize HRV and RSA. Breathing pattern was assessed using the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo manual palpation techniques in 83 people with possible dysfunctional breathing before they attempted HRV biofeedback. Mean respiratory rate was also assessed. Subsequently, participants applied a brief 5-minute biofeedback protocol, involving breathing and positive emotional focus, to achieve HRV patterns proposed to reflect physiological "coherence" and entrainment of heart rhythm oscillations to other oscillating body systems. Thoracic-dominant breathing was associated with decreased coherence of HRV (r=-.463, P= .0001). Individuals with paradoxical breathing had the lowest HRV coherence (t(8)= 10.7, P = .001), and the negative relationship between coherence of HRV and extent of thoracic breathing was strongest in this group (r= -.768, P= .03). Dysfunctional breathing patterns are associated with decreased ability to achieve HRV patterns that reflect cardiorespiratory efficiency and autonomic nervous system balance. This suggests that dysfunctional breathing patterns are not only biomechanically inefficient but also reflect decreased physiological resilience. Breathing assessment using simple manual techniques such as the MARM and Hi Lo may be useful in HRV biofeedback to identify if poor responders require more emphasis on correction of dysfunctional breathing.

Full text: Headnote

Background * Heart rate variability (HRV) biofeedback is a self-regulation strategy used to improve conditions including asthma, stress, hypertension, and chronic obstructive pulmonary disease. Respiratory muscle function affects hemodynamic influences on respiratory sinus arrhythmia (RSA), and HRV and HRV-biofeedback protocols often include slow abdominal breathing to achieve physiologically optimal patterns of HRV with power spectral distribution concentrated around the 0.1-Hz frequency and large amplitude. It is likely that optimal balanced breathing patterns and ability to entrain heart rhythms to breathing reflect physiological efficiency and resilience and that individuals with dysfunctional breathing patterns may have difficulty voluntarily modulating HRV and RSA. The relationship between breathing movement patterns and HRV, however, has not been investigated. This study examines how individuals' habitual breathing patterns correspond with their ability to optimize HRV and RSA.

Method * Breathing pattern was assessed using the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo manual palpation techniques in 83 people with possible dysfunctional breathing before they attempted HRV biofeedback. Mean respiratory rate was also assessed. Subsequently, participants applied a brief 5-minute

biofeedback protocol, involving breathing and positive emotional focus, to achieve HRV patterns proposed to reflect physiological "coherence" and entrainment of heart rhythm oscillations to other oscillating body systems.
Results * Thoracic-dominant breathing was associated with decreased coherence of HRV (r=-.463, P= .0001). Individuals with paradoxical breathing had the lowest HRV coherence (t(8)= 10.7, P = .001), and the negative relationship between coherence of HRV and extent of thoracic breathing was strongest in this group (r= -.768, P= .03).
Conclusion * Dysfunctional breathing patterns are associated with decreased ability to achieve HRV patterns that reflect cardiorespiratory efficiency and autonomic nervous system balance. This suggests that dysfunctional breathing patterns are not only biomechanically inefficient but also reflect decreased physiological resilience. Breathing assessment using simple manual techniques such as the MARM and Hi Lo may be useful in HRV biofeedback to identify if poor responders require more emphasis on correction of dysfunctional breathing.
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Breathing patterns are strongly influenced by disease processes of the respiratory and cardiovascular system12 and by psychological or emotional states.34 Conversely, the presence of balanced breathing patterns may reflect physiological resilience and efficiency and thus contribute to self-regulation and health maintenance. It has been suggested that breathing contributes to health maintenance via its influence on respiratory sinus arrhythmia (RSA) and thus heart rate variability (HRV); however, the relationships between breathing movement patterns and HRV have not been explored.5

HEART RATE VARIABILITY AND RESPIRATORY SINUS ARRHYTHMIA

The genesis of RSA and HRV is complex, and breathing is one of several factors that influence it. The effects of inhalation and exhalation produce phasic neurological influences that, when integrated with central nervous system rhythmic discharge, autonomic nervous system (ANS) tone, and phasic fluctuations of vagal nerve activity, produce specific characteristics of HRV67 The efficiency of the respiratory pump in creating the phasic fluctuations of blood volumes and vascular pressure that are integral to HRV and RSA is likely to be of importance in optimizing HRV7

Optimizing Heart Rate Variability and Respiratory Sinus Arrhythmia

Optimal HRV is reported to reflect physiological coherence and resonance between mind-body systems.811 Heart rhythm "coherence" is said to occur when HRV becomes dominated by high amplitude peak in the HRV power spectrum and breathing rhythm that is entrained to heart rhythm and characterized by a regular sinusoidal wave pattern.510 This occurs when healthy individuals breathe very slowly, at about 5 to 8 cycles per minute or 0.1 Hz. The increased amplitude of RSA at these slow rates of breathing reflects coordinated function of the respiratory, cardiovascular, and nervous systems and produces beneficial physiological effects for gas exchange, hemodynamics, and ANS function1213 as well as therapeutic benefits for cardiovascular, respiratory, and ANS diseases,1114 along with improved psychological states.1516

Dysfunctions of Heart Rate Variability and Breathing in Disease

HRV and breathing pattern both tend to be abnormal in diseases of the nervous, cardiovascular, and respiratory systems. Many of the conditions treated through teaching individuals how to optimize HRV patterns, including COPD,17 asthma,18 and psychological states of anxiety and depression,151619 can also be successfully treated with breathing therapy.2025 In respiratory, cardiovascular, and nervous system ailments, the attenuation of HRV and RSA is associated with increased mortality and morbidity.626 In chronic respiratory and cardiovascular diseases, breathing pattern is often altered as a result of increased respiratory drive, increased chemosensitivity, and hyperinflation of the lungs.2731

Breathing pattern is also altered in psychological diseases and in chronic stress.33235 Respiratory control, ventilatory drive, and respiratory rhythm generation are altered in response to psychological and emotional states.3'43336 Typical changes in breathing pattern in individuals with psychological stress and nervous system hyperarousal are similar to those seen in respiratory disease and include altered timing of inspiration to

expiration and altered function of the diaphragm and accessory inspiratory muscles.3'32'3738
In individuals with altered breathing pattern, function and coordination of respiratory muscles can be impaired.3940 Typical changes in breathing pattern, resulting from hypertonic accessory muscles of breathing and diaphragm dysfunction, include thoracic-dominant breathing, asynchrony of thoracic to abdominal motion during breathing, and paradoxical breathing.414344 Dysfunctional breathing patterns that might arise due to cardiovascular and respiratory diseases or due to chronic psychological stress can result in learned patterns of muscle use which tend to become habitual.4547
Both dysfunctional breathing patterns and reduction of HRV reflect loss of ANS regulation, decreased ability to return to resting state, and thus reduced physiological resilience and efficiency.
Effects of Respiration on Heart Rate Variability
Research into the specific nature of respiratory influences on RSA has paid little attention to pattern of breathing movement and has focused primarily on the effects of respiratory rate and volume.48 51 Research has consistently shown that slower respiratory rate results in increased amplitude of RS Au'49'5052 and sometimes reports the same effects from increased tidal volumes.4951
Only a small amount of research has investigated the impact of how thoracic, as compared to abdominal or diaphragmatic, mode of breathing affects magnitude of RSA. Reports on how mode of breathing affects the hemodynamic influences on RSA - ie, venous return, stroke volume, and blood pressure - are contradictory and hard to evaluate as they do not describe how the mode of breathing was assessed.7'5354
The assessment of breathing pattern has previously been restricted by the lack of standardized protocols. Recently, a technique called the Manual Assessment of Respiratory Motion (MARM) has been found to be reliable and to enable standardized reporting of thoracic to abdominal balance in breathing pattern.5556
Previous studies with the MARM have shown that healthy individuals tend to have a balanced breathing pattern with relatively equal motion between the upper rib cage and the lower rib cage/abdominal compartment.55
Another technique used in this study, called the Hi Lo, is used to detect paradoxical breathing and is representative of the type of clinical procedure long used by clinicians to detect the presence of paradoxical breathing.5758 The Hi Lo has been shown to be reasonably accurate in detecting simulated paradoxical breathing.56 We propose that at rest, balanced breathing with synchronous motion of the upper rib cage with the lower rib cage and abdomen is the most biomechanically efficient and functional breathing pattern that allows the greatest flexibility of respiratory response. Presence of this type of breathing pattern may correspond to greater physiological resilience as evidenced, for example, by greater ability to achieve HRV coherence.
There are various HRV biofeedback protocols using a range of strategies to achieve target amplitudes and frequencies of HRV Protocols usually include cognitive strategies as well as slow abdominal and diaphragmatic breathing.1459 In clinical practice, it is often seen that some individuals have problems breathing abdominally and diaphragmatic ally. While anterior displacement of the abdominal wall is generally a sign of diaphragm contraction, in individuals with compromised breathing, instruction to breathe with the abdomen can reduce diaphragm efficiency.2560 Individuals with compromised efficiency of respiratory muscles are most likely to have trouble modulating breathing and are also more likely to present with breathing pattern disturbances.
Breathing patterns that are commonly associated with dysfunctional breathing may affect ability to achieve features of HRV and RSA associated with coherence. The aim of this study is to investigate the relationship of spontaneous respiratory rate, presence of paradoxical breathing, and extent of thoracic breathing to individuals' response to a biofeedback protocol that aims to increase amplitude and power spectral density of HRV around the 0.1-Hz frequency.
It is hypothesized that individuals with features of dysfunctional breathing such as greater resting thoracic breathing, increased respiratory rate, and paradoxical breathing will be less able to achieve target amplitudes and frequencies of HRV.
METHOD

Participants

Of the 83 individuals who participated in this study, 29 were male and 54 were female, and the average age was 49 years. They were either healthy or suffered from mild medical conditions including mild asthma. Twenty-nine of these participants were found to have abnormal spirometry defined by either forced expiratory volume in 1 second or forced vital capacity greater than 15% below predicted.

They had volunteered for a larger study, which was advertised as an investigation into breathing dysfunction. AU participants gave signed consent. The Human Research Ethics Committee of the Royal Melbourne Institute of Technology University approved the study.

The sample size was determined from a power analysis, which estimated that detecting a significant correlation between breathing measures of 0.3 with 80% power and significance level of .05 would require 85 participants.

Data Collection and Analysis

Heart Rate Variability. Heart rate measurement was undertaken using ear sensor photoplethysmography (Quantum Intec, Ine, Boulder Creek, California). Initial heart rate data were recorded as two time-domain measures, R-R intervals (the time measurement between the R wave of one heartbeat and the R wave of the preceding heartbeat) and total number of beats. HRV data were converted to the frequency domain using spectral analysis (Fast Fourier Transform) by the Freeze Framer software (Quantum Intec, Ine). Power spectral density of HRV was determined in three frequencies: a very low-frequency component (<0.04 Hz), a mid-to-low frequency component (0.04-0.26 Hz), and a high-frequency component (>0.26 Hz). Total power was calculated as the variance of the whole signal over all three frequencies.

The Quick Coherence Test. During this 5-minute test, participants were asked to observe a computer screen that showed the HRV waveform patterns and a screen with color bars representing percentages of high, medium, and low coherence. They were told to increase the amount of high coherence by using the Quick Coherence Technique.9,59 Participants were given the following instructions:

Focus your attention in the area of your heart. Pretend you are breathing slowly and gently through your heart for a count of 5 or 6. While continuing to breathe through your heart, find a positive feeling or attitude like care, compassion or appreciation.59

Statistical Calculation of Heart Rhythm Coherence Variables. The Freeze Framer software was used to calculate heart rhythm coherence variables. Coherence variables represent the concentration of HRV around the 0.1-Hz spectral range and amplitude of the HRV wave at this frequency. The calculation for quantifying coherence identifies the maximum peak in the 0.04 to 0.26 range. Peak power is then determined by calculating the integral in a window 0.03-Hz wide, centered on the highest peak in that region. The total power of the entire spectrum is then calculated. The coherence ratio is formulated as Peak Power/(Total Power-Peak Power)2 (Figure).

Scores for high, medium, or low coherence are given on the basis of this calculation. Low coherence scores are <0.9, medium coherence between 0.9 and 7, and high coherence >7. Percentages of low, medium, and high coherence are then calculated on the basis of these thresholds. These calculations are explained in detail elsewhere.9

The term coherence can be used to refer to either crosscoherence, which is the phase relationship between two oscillators, or to autocoherence, which describes the characteristics of a single oscillation.6163 When describing a single system such as HRV, autocoherence refers to the characteristics of stable frequency, amplitude, and shape of waveform created by oscillations arising from this system.15

Breathing Pattern. Respiratory Rate. Arterial oxygen (SPO2) and end tidal CO2 (ETCO2) measures were made using a combined capnometer and pulse oxymeter (BCI Capnocheck, Smiths Medical, St Paul, Minnesota). Spontaneous rate of breathing was calculated from fluctuations in SPO2, and ETCO2. The equipment was regularly calibrated and checked for accuracy with a known gas mixture.

ETCO^sub 2^, SPO^sub 2^, and respiratory rate (RR) were measured for about 25 minutes while the participant completed various questionnaires. After excluding data from the first 2 minutes to allow for the participant settling in, the average measures were calculated for each variable.

The Manual Assessment of Respiratory Motion. The MARM was used to quantify the extent of thoracic dominance in breathing. The MARM procedure, which has been described previously,55 allows the examiner to record a graphic representation of their impression of upper rib cage and vertical motion relative to lower rib cage/abdomen. From the examiner's graphic notation, a numerical value called balance can be derived. Values of balance close to zero indicate equal participation of thoracic and abdominal parts to breathing. The MARM balance measure has been demonstrated to have good interexaminer reliability, consistency with measures performed using respiratory induction plethysmography (RIP), and ability to differentiate breathing patterns.55

Assessment of Paradoxical Breathing With Hi Lo Technique. The Hi Lo technique of visual and manual breathing assessment was used to determine persistence of paradoxical breathing despite instruction to "breathe into the belly."

When performing the Hi Lo, the examiner's hands are placed on the anterior central upper chest and clavicular area (Hi) and the anterior upper abdomen (Lo). From this hand position, the examiner can determine the dominance and coordination of upper chest to lower chest and abdominal motion during inspiration and expiration phases of the respiratory cycle.56

Participants were asked to take in a slightly deeper breath than usual and to direct this breath into the lower chest and abdomen so that the abdomen moved outward and the lower chest widened. Participants who, despite instruction, continued to initiate the breath with upper chest motion and who drew the abdomen inward during inhalation were classified as paradoxical breathers.

Procedure

Each participant attended one session during which all data were collected. Participants were given the series of questionnaires to fill out while attached to the capnometer. This device was used to continuously measure ETCO2, SPO2, and respiratory rate over approximately 25 minutes. The MARM was performed, followed by the Hi Lo paradoxical breathing assessment. Subsequently, HRV biofeedback was performed and participants were given instructions on how to perform the quick coherence technique.

RESULTS

Descriptive statistics for the entire sample and for the subsets who demonstrated (n = 8) and who did not demonstrate (n = 75) paradoxical breathing at the time of the study and the results of the independent t-tests comparing the two subsets are shown in Table 1.

A number of measures differed significantly between paradoxical and nonparadoxical subsets. Paradoxical breathers had higher values for respiratory rate, more thoracic breathing shown as higher score for MARM balance variable, higher values for QCT-low (indicating less coherence) and lower values for QCThigh (also indicating less coherence), and unexpectedly lower heart rates.

For the full sample (n = 83), significant correlations were found between thoracic dominance (high MARM balance scores) and two coherence scores (QCT-low coherence scores, r=.463, P = .0001; QCT-high coherence scores, r = -418, P =.0001). This is shown the upper quadrant of Table 2.

Correlations were calculated separately for the group found to have paradoxical breathing. These are shown in the lower quadrant of Table 2. In this group, thoracic dominance (MARM balance score) had much higher correlations with both QCT-low coherence scores, r=.724, P=. 042, and QCT-high coherence scores, r= 746, P= .027. Individuals with paradoxical breathing had the lowest HRV coherence (t[8] = 10.7, P= .001)

DISCUSSION

This study explored the relationship between three components of breathing pattern (thoracic dominance, presence of paradoxical breathing, and respiratory rate) and ability of individuals to produce HRV with features of "coherence" or "resonance." It was found that individuals' resting breathing pattern is related to their ability to quickly achieve HRV coherence. The more equal the balance between upper thoracic and lower thoracic/abdomen breathing motion during the person's habitual breathing, the greater the extent of HRV coherence achieved. Individuals with upper thoracic-dominant breathing achieved less coherence during the 5-minute quick coherence technique, and the extent of upper thoracic breathing was inversely related to their ability to produce HRV coherence. Individuals with paradoxical breathing had the strongest negative correlation between coherence and upper thoracic breathing and as a group achieved significantly lower coherence levels during the biofeedback protocol.

Our data did not demonstrate any significant relationship between the individuals' spontaneous breathing rate before the biofeedback procedure and their ability to achieve target HRV during the biofeedback task. To our knowledge, only one other study has investigated the effects of spontaneous rate of breathing on RSA response to respiratory modulation, and those results did show a relationship.64 Therefore, while a relationship between spontaneous rate of breathing and RSA may exist, its effect may not be as strong as that of a balanced and synchronous breathing pattern.

More balanced breathing patterns were associated with greater ability to achieve HRV coherence, and unbalanced breathing patterns were associated with decreased ability to a achieve coherence. Relatively balanced motion between thoracic/ upper ribcage and abdominal/lower rib cage compartments during relaxed breathing seems to be characteristic of healthy individuals with good breathing control.55 The increased speed and ability with which individuals in this study with balanced and nonparadoxical breathing achieved coherence suggests that balance of thoracic-to-abdominal breathing with synchronous expansion of upper rib cage and lower rib cage during inspiration represents the most functional breathing pattern for individuals at rest. Similarly, those with unbalanced breathing patterns may be said to have greater breathing dysfunction. Breathing functionality is reflected in the ability of individuals to control and modify their breathing. In this sample, individuals with paradoxical breathing who were unable to follow instructions to "expand the belly and lower rib cage during inspiration" had the most dysfunctional breathing. Decreased ability of these individuals to achieve optimal levels of HRV coherence suggests that loss of breathing self- regulation is associated with loss of other aspects of self- regulation as reflected in this study in decreased ability to regulate autonomic and cardiorespiratory homeostatic reflexes involved in achieving HRV coherence.

In individuals with balanced, nonparadoxical breathing, the increased ability to produce HRV coherence probably is linked to greater efficiency of the respiratory pump in generating the pressure and blood flow fluctuations needed for activation of RSA. This state of balance may also reflect a greater homeostatic range that provides a greater flexibility of response and hence "respiratory resilience." Presence of thoracic-dominant and paradoxical breathing may be indications that the diaphragm is not functioning with optimal length and strength.6065 Optimal diaphragm function is needed to maximize the differences between pleural and abdominal pressures that stimulate large fluctuations in venous return to the heart and activate the vascular reflexes that produce RSA.60 It is well known that during normal inspiration, a drop in intrathoracic pressure, assisted by an increase of intraabdominal pressure, promotes increased return of venous blood to the heart and stimulates RSA.7 Alterations in normal respiratory pressures development during positive pressure ventilation have been shown to result in reduced filling of the right atrium, decreased left ventricular stroke volume, and reduced RSA.6668 Thoracic-dominant breathing tends to affect the rate of pressure development by the inspiratory muscles and may affect RSA in that way.47 If, as in paradoxical breathing, the abdomen draws in during inspiration, there is a decrease in abdominal pressure during inspiration resulting in abnormal filling of thoracic blood vessels returning venous blood to the heart.69

The findings of this study may be clinically relevant when dealing with patient groups such as those with asthma, COPD, anxiety, and depression who are more prone to abnormal breathing patterns and have more difficulty with respiratory control. In conditions such as asthma and COPD, increases in respiratory drive and central motor outflow to respiratory muscles result in tonic contraction of the inspiratory muscles, including the diaphragm, producing changes in respiratory pattern.3970 Some of the changes in respiratory muscle function affect efficiency of breathing functions71 and may affect respiratory control by altering feedback from phrenic and other respiratory muscle afférents.72 This may be the case in some individuals with COPD who, when instructed to follow breathing instructions, develop more paradoxical breathing and increased dyspnea.25 Individuals with other diseases of obstructed breathing such as asthma also might have problems with respiratory control resulting from biomechanical inefficiency resulting from hypertonic inspiratory muscles and impaired diaphragm function.7374 Clinical management of these patients may be improved by regular monitoring of breathing pattern with techniques such as the MARM and Hi Lo.

Attention to breathing patterns may improve response to HRV biofeedback in patients with stress and anxiety disorders who also have breathing pattern disorders. Stress is known to affect the response of HRV to respiratory modulation,6'7576 and any additional limitations arising from poor ability to control respiration may be particularly important in these patients. Increased arousal and sympathetic nervous system activity directly increase phrenic nerve activity and consequently diaphragm tone.3236 Fluoroscopic studies have shown that stress results in the diaphragm becoming shortened and flattened.3738 A shortened, flattened, and hypertonic diaphragm is associated with paradoxical breathing and thoracic-dominant breathing and thus reduced flexibility of response.71 In some individuals, the effects of stress on the diaphragm may alter its function and its relationship to the function of other respiratory muscles resulting in changes of thoracic-dominant and paradoxical breathing.

The MARM and Hi Lo used in this study to assess breathing pattern are two simple clinical approaches used to assess breathing pattern. The Hi Lo may be most useful for assessing the gross asynchrony of motion of thoracic and abdominal compartments during breathing that is often associated with diaphragm dysfunction.56 The MARM appears to assess more subtle diaphragm dysfunction, evidenced by loss of lateral expansion of the lower rib cage and consequently with loss of balanced motion of between upper and lower rib cage.606577

Limitations

This study used the Freeze Framer, a device that measures HRV through ear sensor photoplethysmosgraphy. The spectral analytic variables measured by photoplethysmography are derived from interbeat intervals and are not the usual statistical indices measured in HRV research. Circumstances did not allow the conversion of the raw interbeat interval data to more established variables. However, this study did show that relationships exist between specific breathing pattern and the individual's ability to concentrate power of HRV in the target low-frequency spectral range (around 0.1 Hz). Ideally, this study would be repeated using EKG data and variables computed from R-R intervals.

The MARM and Hi Lo also are clinical rather than research tools and require further validation. However, their strength lies in the ease with which they can be implemented in regular clinical practice of HRV biofeedback.

CONCLUSION

Aspects of breathing pattern such as synchrony and balance of thoracic-to-abdominal motion during breathing, which appear to provide a greater respiratory resilience and flexibility of response, are important for HRV response. Breathing assessment using simple manual techniques such as the MARM and Hi Lo may be useful in HRV biofeedback to assess responders, particularly in symptomatic populations. Also, HRV biofeedback may benefit from more emphasis on breathing training to achieve more balance and synchrony of thoracic and abdominal breathing.

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