

# The Interplay of Breath and Emotion: A Novel Cardio-Respiratory-Cortical-Limbic Network Framework

Ravinder Jerath<sup>1</sup>, Michael Jensen<sup>2</sup>

<sup>1</sup>Mind-Body Technologies, Augusta, USA

<sup>2</sup>College of Allied Health Sciences, Augusta University, Augusta, USA

Email: [beveridge.connor00@gmail.com](mailto:beveridge.connor00@gmail.com)

**How to cite this paper:** Jerath, R., & Jensen, M. (2025). The Interplay of Breath and Emotion: A Novel Cardio-Respiratory-Cortical-Limbic Network Framework. *Psychology*, 16, 453-465.

<https://doi.org/10.4236/psych.2025.164025>

**Received:** February 27, 2025

**Accepted:** April 13, 2025

**Published:** April 16, 2025

Copyright © 2025 by author(s) and  
Scientific Research Publishing Inc.

This work is licensed under the Creative  
Commons Attribution International  
License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

---

## Abstract

The lung's influence on our emotional well-being, beyond its primary role in respiration, remains a compelling scientific mystery. Here, we put forth a unique perspective: emotional coordination and regulation are actively influenced by the bioelectric rhythms between respiratory and cardiac activities. Current models emphasize the cognitive basis of emotions, but we posit that dysfunctional breathing patterns can directly drive and amplify emotional experiences. Research suggests that persistent anxiety states are linked to instable, shallow, and irregular breathing. Key neurotransmitters involved in emotional regulation are also found within the lungs and heart, further supporting a direct physiological link as an extension of the limbic system. We believe that the brain-stem's cardio-respiratory center, through continuous engagement, fluctuates limbic and other brain regions, creating a cardio-respiratory-cortical-limbic network. This network, supported by bioelectric rhythms, plays a pivotal role in generating and amplifying emotions; synchronized rhythms give rise to distinct experiences such as anxiety or joy. Chronic abnormal breathing patterns, evident in emotional disorders, play a pivotal role in perpetuating negative emotional states. We propose a potential therapeutic intervention: 6 slow, deep breaths per minute could disrupt negative emotional patterns. This perspective offers a new understanding on emotional coordination and the potential for respiration-focused therapies for stress and anxiety disorders.

## Keywords

Anxiety, Depression, Chronic Abnormal Breathing, Bioelectric Oscillations, Lung-Emotion Connection, Neurotransmitters in Lungs, Cardio-Respiratory-Cortical-Limbic Network, Therapeutic Potential of Controlled Breathing

---

## 1. Introduction

The lungs, commonly recognized as vital organs for oxygenation, have historically been predominantly studied in relation to their role in respiratory function (Haddad, 2023). We present an alternative perspective by emphasizing the complex and profound function of the lungs in restraining the development of whole human emotions and promoting mental well-being (Zaccaro et al., 2018).

Here, we attempt to reveal undiscovered aspects of how the lungs impact our emotional experiences opposing the prevailing emphasis on individual thoughts or cognitive evaluations in the comprehension of emotions (Jerath & Beveridge, 2020). Although cognition has historically been the main focus of talks on emotions, there is an increasing acknowledgment that emotional states are more complicated than just cognitive processes (Izard, 2009). The revelation of the lungs' impact is presented as a deviation from the conventional storyline, which frequently neglects the physiological organs while discussing emotions (Jerath & Beveridge, 2020; Von Leupoldt et al., 2010). We hope to inspire a more thorough investigation into the physiological basis of our emotional experiences by questioning the prevailing cognitive-focused viewpoints. The view that the lungs play a crucial role in this complex connection between the mind and body has been previously presented (Lee et al., 2017).

## 2. A Novel Perspective on the Cardiorespiratory System

The perspective we put forth presents an innovative viewpoint on the correlation between physiological processes and emotional experiences. The core of this argument is the idea that emotional reorganization, the complex process through which emotions establish and endure, heavily depends on the interaction between respiratory and cardiac bioelectric rhythms (Maric et al., 2020; Ashhad et al., 2022). The renowned Cannon-Bard theory postulates that emotions and bodily reactions occur concurrently but independently (Friedman, 2009). This perspective contradicts previous theories that largely focus on cognitive and psychological aspects by proposing that emotional states are tightly connected to the synchronized rhythms of breathing and heartbeat (Jerath & Beveridge, 2020). Entrainment refers to the synchronized cooperation between the respiratory and cardiac systems, indicating that the time and rhythm of our breath and heartbeat may have a significant impact on our emotional state (Trost & Vuilleumier, 2013).

Abnormal breathing patterns may play an active role in increasing and intensifying emotional experiences (Vidotto et al., 2018, 2019). This creates a dynamic interaction between the physiological process of breathing and the unfolding emotional reactions. Dysregulations in breathing appear to be not simply incidental, but rather play an active role in regulating the intensity and duration of emotional emotions (Pace-Schott et al., 2019). The intricate web of nerves in the body has a significant effect on heart rate, rhythm, and brain activity. One study investigated how focusing on internal bodily signals (interoceptive attention) influences how the brain processes heartbeat information (heartbeat-evoked poten-

tial) during different breathing phases (inhalation and exhalation). They found that people were better at detecting their heartbeats and had stronger brain responses to them when they were exhaling compared to inhaling. This effect was independent of the person's heart rate itself. This suggests that paying attention to our internal signals and breathing can improve how well our brain communicates with our heart (Zaccaro et al., 2022).

We aim to elucidate the relationship between respiratory patterns, limbic system activity, and emotional processing, with a particular focus on the impact of nasal breathing. Research to support this perspective might have participants experience four experimental conditions in a counterbalanced order: baseline with neutral stimuli and natural breathing; emotional stimuli with natural breathing; emotional stimuli with controlled slow deep nasal breathing (6 breaths/min); and emotional stimuli with simulated stress rapid shallow breathing. Each condition will last 10 minutes, interspersed with 5-minute rest periods, followed by fear discrimination and emotional memory recognition tasks (Ojeda Valencia et al., 2023). Various measurement techniques, including respiratory inductance plethysmography to record waveforms, EEG and fMRI could be employed to analyze brain activity focusing on limbic structures and the piriform cortex, ECG to assess heart rate variability, and the Self-Assessment Manikin (SAM) for emotional self-reports. Data analysis might involve time-frequency analysis of EEG to identify limbic high-amplitude potential waves (HAP-waves), cross-correlation of these waves with respiratory rhythms, and functional connectivity analysis using fMRI.

We hypothesize that limbic HAP-waves will show increased synchronization with respiratory rhythms during nasal breathing, leading to improved performance in fear discrimination and emotional memory tasks, enhanced connectivity between the piriform cortex and limbic structures, and more effective emotional regulation as indicated by self-reports and physiological measures (Zelano et al., 2016). Such research would demonstrate how respiratory patterns have a deep influence on emotional control and neurological balance. The available evidence substantiates the concept, emphasizing the impact of bioelectric activity originating in the lungs on emotional experiences and the regulation of the autonomic nervous system.

### 3. Breath-Brain and Heart Entrainment

We propose an immediate and direct connection exists between the lungs, heart, and brain. This connection extends beyond the physical structure of blood vessels and nerves and involves the bioelectric activity that is initiated with every breath. By harnessing these bioelectric connections, we can manipulate the emotions formed in the brain, transforming them from brief and transitory sensations into persistent and severe states of worry or sadness. When we inhale, it is not solely the expansion and contraction of our lungs. An electrical surge propagates across the human body, exerting an impact on several physiological processes such as heart rate and brainwave patterns (Boyadzhieva & Kayhan, 2021; Kim et al., 2013).

When the diaphragm contracts and the lungs expand, stretch receptors in the lungs transmit electrical signals to the brainstem (Brinkman, 2023). One possible explanation is that the dynamic mechanical activity of stretch receptors in the lungs, together with redox reactions occurring mainly at the location of gas exchange, generate electrical currents that are utilized throughout the entire body (Jerath & Beveridge, 2018). The immense quantity of electrons in these currents originates from the oxygen we inhale, which amounts to  $6 \times 10^{23}$  molecules of  $O_2$  (Jerath & Beveridge, 2018). These particular redox reactions and activity that we are describing predominantly take place at the site of gas exchange in the alveoli. The immediate impact of these events on the body and mind is in stark contrast to the several seconds it takes for blood to circulate throughout the body. Historically, the communication between the lungs and the brain was believed to occur through neural channels, specifically the vagus nerve. Recent investigations have uncovered a more complex understanding, showing that non-neuronal components like blood vessels, epithelial cells, and immune cells play a significant role. Despite the severance of both vagus nerves, research indicates that breathing signals continue to reach the brain, indicating the presence of alternate pathways (Dick et al., 2008; Jerath & Beveridge, 2018).

In the brainstem, the signals interact with various centers, including the cardiac and respiratory centers (Breit et al., 2018). These centers generate their electrical rhythms that synchronize with the incoming signals from your breath. This creates a unified wave of bioelectric activity that spreads throughout your body. This network of nerves carries the signal to the heart, influencing the heart rate and rhythm (British Heart Foundation, n.d.). A deep breath might slow the heart down, while a quick shallow one might speed it up (Russo et al., 2017). The brainstem reticular formation acts like a relay station, sending the signal to various brain regions like the hypothalamus, thalamus, and cortex. This influences alertness, mood, and cognitive functions (Wolff et al., 2021). As the wave of bioelectric activity reaches different organs and tissues, it interacts with its electrical rhythms, adjusting their activity to match the overall rhythm of breath (Harris, 2021). This creates a unified platform of electrical signals, where breath acts as the lever, influencing the functions of your entire body.

#### **4. Breath's Role Is Emotional Regulation and Neurological Harmony**

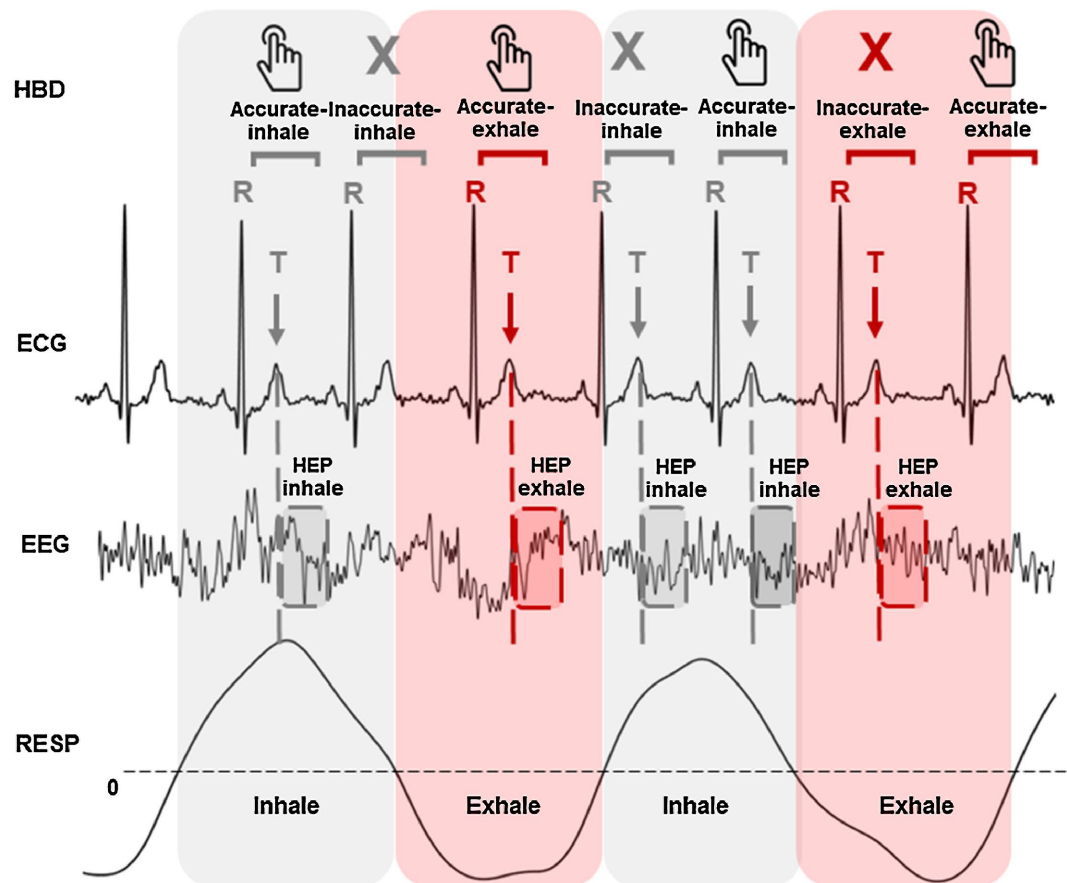
The complexities of the human brain exhibit significant challenges when it comes to direct observation and control. The contemporary understanding about brain changes associated with emotions is unclear, entirely observed at the neuronal level and involving extensive neural networks (Lisman, 2015). While providing valuable insights into brain activity, traditional imaging techniques have limitations in capturing the real-time dynamics of emotional processing. The complex interaction of neurotransmitters, neural circuits, and synaptic connections remains challenging to observe directly, making it difficult to intervene precisely at

the neural level (Owens & Tanner, 2017). However, the challenges associated with directly observing and controlling brain changes open the door to alternative ways of understanding and modulating emotions, with the respiratory system emerging as a realistic and approachable entry point (Heck et al., 2022; Maric et al., 2020).

People do not have control over generating anxiety or depression-triggering events as part of their life, however, one can control emotions to reorganize and become life-changing emotional states through controlled breathing. Conscious and manageable, breathing establishes a strong connection between the mind and body, enabling transformative emotional states. Individuals can consciously alter their breathing patterns, and these alterations, in turn, exhibit predictable changes in emotional states (Boyadzhieva & Kayhan, 2021). The predictability and moldability of respiratory patterns make them an appealing target for interventions aimed at emotional control (Noble & Hochman, 2019; Buchanan & Janelle, 2022). The valid reason is that breathing has a tremendous impact on the peripheral, autonomic, and central neurological systems through bioelectric rhythms, in addition to its traditional role in gas exchange (Guyenet, 2014; Russo et al., 2017). Further, this effect is manifested by a stunning interplay of quick movements generated by each breath, which promotes long-term potentiation and fortifies receptors throughout the body (Law & Leung, 2018, 2020). Changes in EEG (Electroencephalography), ECG (Electrocardiography), and EMG (Electromyography) demonstrate the pervasiveness of breathing-related bioelectric processes (Figure 1) (Valentinuzzi, 2007; Martinek et al., 2021).

The synchronized bioelectric rhythms spread from the lungs to the brainstem cardiac and respiratory centers and create a balanced mind-body state which can calm down emotional disturbances (Figure 2) (Jerath & Crawford, 2015). However, our novel view challenges this perspective by proposing that the origin of bioelectric activity is rooted in fast oscillating currents originating in the lungs. The immediate alterations observed in the SA node, gamma and alpha waves, muscles, and skin after each breath imply a direct connection to bioelectric activity. Existing research delves into the implications of these breathing-related electrical currents for maintaining homeostasis, influencing emotions, and regulating the autonomic nervous system (Folschweiller & Sauer, 2021). It supports our perspective that these currents, particularly generated during inspiration, may permeate the body, impacting bioelectric activity and contributing to various physiological functions.

The influence of respiratory patterns extends beyond the lungs, impacting the cardiovascular system and brain. Additionally, controlling respiration directly affects heart rate and heart rate variability (HRV) (Balban et al., 2023). Some research shows that focused breathing can change gamma and alpha waves through bioelectric activity, which show changes in brain activity related to focus, relaxation, and controlling emotions (Dobrakowski et al., 2020; Gao et al., 2023). The interconnectedness of the respiratory, cardiovascular, and neural systems highlights the potential for targeted interventions through controlled breathing,



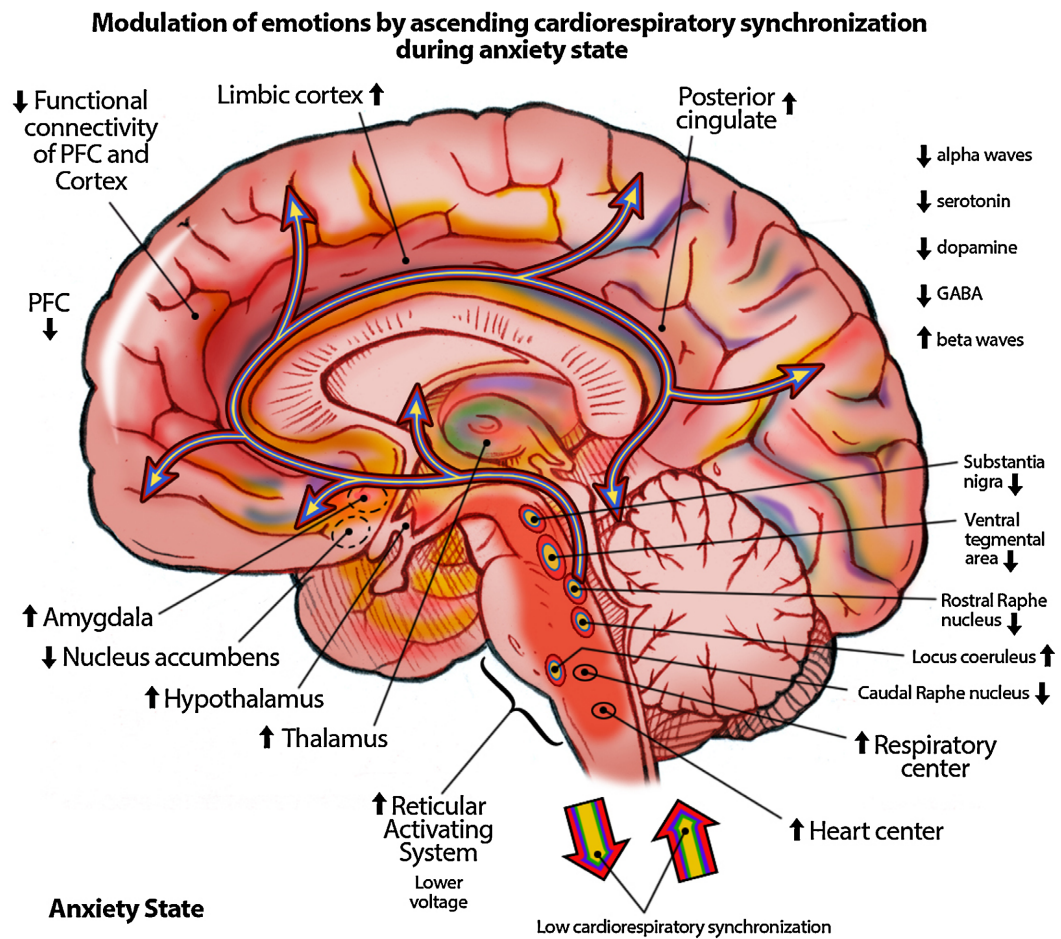
The image is a diagram of the proposed gradient of predictive oscillations in respiratory, heart and brain coupling with ECG (electrocardiogram), EEG (electroencephalogram) changes at each breathing cycle. The authors argue that respiration generates anticipatory signals that influence brain activity at multiple levels, from the brainstem to the cortex. These anticipatory signals allow the brain to predict and synchronize with upcoming respiratory events, facilitating efficient communication and coordination between the respiratory system and the brain.

**Figure 1.** Predictive oscillations in the lungs, heart and brain.

providing individuals with an immediate way of influencing their emotional well-being (Weng et al., 2021; Campanelli et al., 2020). Emotions can be controlled by predicting and altering breathing patterns, subsequently affecting heart rate, heart rate variability, and brain waves. The process of emotional internalization is highly dependent on the coordination of respiratory and cardiac rhythms. There is a connection between persistent anxiety states and abnormal, shallow, and irregular breathing patterns that become synchronized (Oku, 2022).

## 5. Neurotransmitter Evidence

The intricate connection between emotional regulation and respiratory physiology is substantiated by the presence of key neurotransmitters associated with emotional states in both the lungs and the heart. The bioelectric rhythms generated in the lung spread to the whole body, including the brain, and vice versa. Key neurotransmitters involved in emotional processes secreted locally in the lung



Modulation of emotions by ascending CRC during the anxiety state. The figure illustrates the widespread activation of the emotion-related areas of the brain when low CRC levels exist (i.e., the levels are not strong enough to cause inhibition). Decreases in the activity in the rostral raphe nucleus and caudal raphe nucleus occur that result in lower levels of serotonin and decreases in activity in the ventral tegmental area, substantia nigra, and nucleus accumbens. That decreased activity results in lower levels of dopamine. Increases in the activity in the locus coeruleus also result in higher levels of norepinephrine being released. Decreases also occur in the inhibitory neurotransmitter GABA. Alpha waves, which are associated with relaxed mental states, decrease, and beta waves, which are associated with anxiety, increase. Also, the functional connectivity of the PFC and other cortical areas decreases, and activity throughout the limbic system increases. The available evidence lends support to the hypothesis that low CRC levels are unable to inhibit the activity of the emotion-related areas of the brain; rather, an increased heart rate and respiration rate and increased desynchronization result in a feedback loop that leads to increased activation of the emotion-related areas.

**Figure 2.** Modulation of emotions in anxiety.

work as an extension of the limbic system. The stretch receptors of the lungs and neural elements within these organs are identified as loci-containing neurotransmitters such as GABA, glutamate, glycine, and acetylcholine (Bonham, 1995; Haji, 2008). The inhibitory neurotransmitter GABA typically reduces neuronal activity. Its presence in the lungs suggests it might dampen emotional responses, promoting calmness and relaxation (Abdou et al., 2006; Kuo et al., 2022; Schnorbusch et al., 2013). On the other hand, glutamate, glycine, and acetylcholine increase emotional responses if they accumulate over time. The neuroendocrine cells secrete

dopamine, serotonin, and gastrin-releasing peptides (Gu et al., 2014). The bioelectric activity of the body plays a role in triggering neuroendocrine cells to release dopamine and serotonin neurotransmitters. Chemical changes convert into electrical changes, which entrain the heart-lung with brain waves and change our emotional experience.

The most common neurotransmitters found in both the lungs and brain include dopamine, glutamate, GABA (gamma-aminobutyric acid), norepinephrine (noradrenaline), and acetylcholine, with dopamine playing a particularly significant role in lung function as well as brain activity. Further supporting our perspective, the existence and functionality of the cardio-respiratory center in the brainstem come into focus. This center is revealed as a pivotal transporter, producing continuous bioelectric oscillations that extend beyond mere respiratory control (Folschweiller & Sauer, 2021; Jerath et al., 2019). The coordinated engagement of the cortex, limbic system, hippocampus, heart, and respiratory system is unveiled as a collaborative effort to generate distinct emotional experiences (Rolls, 2019; Arias-López et al., 2020). Our brains create the feeling of an emotion, but it can be dominated through the lungs in a bidirectional way—it's like a unique connection. Emotions themselves oversee how we feel (Tyng et al., 2017). Imagine it as a connection between our breath, attention, and the teamwork of our brain and heart. It's like they're all talking to each other to create the way we experience emotions.

## 6. Implications

The respiratory rhythm coordinates activity in brain regions associated with emotion, memory, consciousness, and sensory processing. It functions as a facilitator that coordinates many regions of the brain (Ashhad et al., 2022). Alterations in respiratory patterns can have a direct impact on brain functionality. Quick respiration can intensify feelings of anxiousness, whereas slow and deep breaths might facilitate calm and enhance concentration (Zaccaro et al., 2018). When the ratio between the pace of breath and the rate of heartbeats is 1:1.5 or 1:2, anxiety levels rise. Therefore, it highlights the significance of breathing in the manifestation of worry. Research indicates that the relaxation response is heightened when the ratio of breathing rate to heart rate is 1:5 or 1:6 (Dobrakowski et al., 2020). Defective breathing plays a significant role in intensifying and prolonging emotional experiences; thus, it is crucial to address and comprehend breathing patterns as a key component of therapies for emotional well-being.

The identification of each 10-second breath (6 breaths/min) as a potential self-regulation strategy introduces a practical and accessible tool for individuals seeking to manage their emotional states (Zaccaro et al., 2018; Dobrakowski et al., 2020; Fincham et al., 2023). When healthy participants were induced to breathe periodically (alternating short bursts of rapid breaths with pauses), their blood pressure and heart rate fluctuated in sync with their breathing. These fluctuations were most pronounced during the apneic (pause) periods, with decreased blood

pressure and heart rate compared to the hyperventilation (rapid breath) periods. Notably, these synchronized oscillations occurred even when participants maintained adequate oxygen and carbon dioxide levels, suggesting that the breathing pattern itself, independent of hypoxia or hypercapnia, influenced cardiovascular activity. Our hypothesis may be empirically verified by molecular studies proving energy release from redox reactions as well as psychological studies correlating brain activity with breathing patterns. If the hypothesis is verified, structured breathing exercises may become a first-line treatment for many psychological disorders.

## 7. Conclusion

This article introduces a new perspective on the nature of emotions. It suggests that breathing isn't just a physical process but is linked to our emotional state. This model differs greatly from existing cardio-respiratory interaction models by describing how energy is harvested in the lungs and how this energy orchestrates synchrony among the heart, lungs, and brain. When we're stressed or anxious, our breathing becomes irregular. This irregular breathing can actually make us feel worse. On the other hand, by taking slow, deep breaths, we can potentially calm ourselves down. The paper argues that this mind-body connection has a physiological basis in the brain, heart, and lungs working together. This challenges the traditional focus on purely mental approaches to managing emotions.

The potential benefits are exciting. If further research confirms these ideas, it could lead to promising initial non-drug treatments for anxiety and other emotional problems as an integral part of CBT (Cognitive Behavioral Therapy) or alone. Future research should thus be done on how breathing patterns influence various aspects of the mind and body. Breathing skills can be applied to manage future challenges and prevent relapse in simple forms of anxiety and depression to several mental disorders such as generalized anxiety disorder, panic disorder, acute stress disorder, and adjustment disorder. This breathing treatment might involve specific breathing exercises that help people regulate their emotions more effectively, paving the way for a more holistic approach to mental health.

## Author Contributions

R. Jerath developed the theory and wrote the abstract and manuscript. M. Jensen has produced an image and reviewed and edited the manuscript. Both authors conducted literature reviews.

## Funding

It is an investigator initiated research. This research was funded by Mind Body Technology, a private organization dedicated to advancing scientific understanding of the mind-body connection and developing innovative technologies to promote health and well-being. Mind Body Technology supports interdisciplinary research initiatives aimed at exploring novel hypotheses and interventions that

integrate physiological and psychological perspectives.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- Abdou, A. M., Higashiguchi, S., Horie, K., Kim, M., Hatta, H., & Yokogoshi, H. (2006). Relaxation and Immunity Enhancement Effects of  $\gamma$ -Aminobutyric Acid (GABA) Administration in Humans. *BioFactors*, *26*, 201-208. <https://doi.org/10.1002/biof.5520260305>
- Arias-López, J. A., Williams, C., Raghvani, R., Aghajani, M., Baez, S., Belzung, C. et al. (2020). The Neuroscience of Sadness: A Multidisciplinary Synthesis and Collaborative Review. *Neuroscience & Biobehavioral Reviews*, *111*, 199-228. <https://doi.org/10.1016/j.neubiorev.2020.01.006>
- Ashhad, S., Kam, K., Del Negro, C. A., & Feldman, J. L. (2022). Breathing Rhythm and Pattern and Their Influence on Emotion. *Annual Review of Neuroscience*, *45*, 223-247. <https://doi.org/10.1146/annurev-neuro-090121-014424>
- Balban, M. Y., Neri, E., Kogon, M. M., Weed, L., Nouriani, B., Jo, B. et al. (2023). Brief Structured Respiration Practices Enhance Mood and Reduce Physiological Arousal. *Cell Reports Medicine*, *4*, Article ID: 100895. <https://doi.org/10.1016/j.xcrm.2022.100895>
- Bonham, A. C. (1995). Neurotransmitters in the CNS Control of Breathing. *Respiration Physiology*, *101*, 219-230. [https://doi.org/10.1016/0034-5687\(95\)00045-f](https://doi.org/10.1016/0034-5687(95)00045-f)
- Boyadzhieva, A., & Kayhan, E. (2021). Keeping the Breath in Mind: Respiration, Neural Oscillations, and the Free Energy Principle. *Frontiers in Neuroscience*, *15*, Article ID: 647579. <https://doi.org/10.3389/fnins.2021.647579>
- Breit, S., Kupferberg, A., Rogler, G., & Hasler, G. (2018). Vagus Nerve as Modulator of the Brain-Gut Axis in Psychiatric and Inflammatory Disorders. *Frontiers in Psychiatry*, *9*, Article No. 44. <https://doi.org/10.3389/fpsy.2018.00044>
- Brinkman, J. E. (2023, June 5). *Physiology, Respiratory Drive*. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK482414/>
- British Heart Foundation (n.d.). *Is the Heart Connected to the Brain*. <https://www.bhf.org.uk/information-support/heart-matters-magazine/research/is-the-heart-connected-to-the-brain>
- Buchanan, T. L., & Janelle, C. M. (2022). Emotions and Ensuing Motor Performance Are Altered by Regulating Breathing Frequency: Implications for Emotion Regulation and Sport Performance. *Frontiers in Psychology*, *13*, Article ID: 963711. <https://doi.org/10.3389/fpsyg.2022.963711>
- Campanelli, S., Lopes Tort, A., & Lobão-Soares, B. (2020). Pranayamas and Their Neurophysiological Effects. *International Journal of Yoga*, *13*, 183-192. [https://doi.org/10.4103/ijoy.ijoy\\_91\\_19](https://doi.org/10.4103/ijoy.ijoy_91_19)
- Dick, T. E., Shannon, R., Lindsey, B. G., Nuding, S. C., Segers, L. S., Baekey, D. M. et al. (2008). Pontine Respiratory-Modulated Activity before and after Vagotomy in Decerebrate Cats. *The Journal of Physiology*, *586*, 4265-4282. <https://doi.org/10.1113/jphysiol.2008.152108>
- Dobrakowski, P., Blaszkiewicz, M., & Skalski, S. (2020). Changes in the Electrical Activity of the Brain in the Alpha and Theta Bands during Prayer and Meditation. *International Journal of Environmental Research and Public Health*, *17*, Article No. 9567. <https://doi.org/10.3390/ijerph17249567>

- Fincham, G. W., Strauss, C., Montero-Marin, J., & Cavanagh, K. (2023). Effect of Breathwork on Stress and Mental Health: A Meta-Analysis of Randomised-Controlled Trials. *Scientific Reports*, *13*, Article No. 432. <https://doi.org/10.1038/s41598-022-27247-y>
- Folschweiller, S., & Sauer, J. (2021). Respiration-Driven Brain Oscillations in Emotional Cognition. *Frontiers in Neural Circuits*, *15*, Article ID: 761812. <https://doi.org/10.3389/fncir.2021.761812>
- Friedman, B. H. (2009). Feelings and the Body: The Jamesian Perspective on Autonomic Specificity of Emotion. *Biological Psychology*, *84*, 383-393.
- Gao, J., Sun, R., Leung, H. K., Roberts, A., Wu, B. W. Y., Tsang, E. W. et al. (2023). Increased Neurocardiological Interplay after Mindfulness Meditation: A Brain Oscillation-Based Approach. *Frontiers in Human Neuroscience*, *17*, Article ID: 1008490. <https://doi.org/10.3389/fnhum.2023.1008490>
- Gu, X., Karp, P. H., Brody, S. L., Pierce, R. A., Welsh, M. J., Holtzman, M. J. et al. (2014). Chemosensory Functions for Pulmonary Neuroendocrine Cells. *American Journal of Respiratory Cell and Molecular Biology*, *50*, 637-646. <https://doi.org/10.1165/rcmb.2013-0199oc>
- Guyenet, P. G. (2014). Regulation of Breathing and Autonomic Outflows by Chemoreceptors. *Comprehensive Physiology*, *4*, 1511-1562. <https://doi.org/10.1002/cphy.c140004>
- Haddad, M. (2023, July 20). *Physiology, Lung*. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK545177/>
- Haji, A. (2008). Respiratory Neurotransmitters and Neuromodulators. In M. D. Binder, N. Hirokawa, & U. Windhorst (Eds.), *Encyclopedia of Neuroscience* (pp. 3467-3470). Springer. [https://doi.org/10.1007/978-3-540-29678-2\\_5076](https://doi.org/10.1007/978-3-540-29678-2_5076)
- Harris, M. P. (2021). Bioelectric Signaling as a Unique Regulator of Development and Regeneration. *Development*, *148*, dev180794. <https://doi.org/10.1242/dev.180794>
- Heck, D. H., Correia, B. L., Fox, M. B., Liu, Y., Allen, M., & Varga, S. (2022). Recent Insights into Respiratory Modulation of Brain Activity Offer New Perspectives on Cognition and Emotion. *Biological Psychology*, *170*, Article ID: 108316. <https://doi.org/10.1016/j.biopsycho.2022.108316>
- Izard, C. E. (2009). Emotion Theory and Research: Highlights, Unanswered Questions, and Emerging Issues. *Annual Review of Psychology*, *60*, 1-25. <https://doi.org/10.1146/annurev.psych.60.110707.163539>
- Jerath, R., & Beveridge, C. (2018). Novel Bioelectric Mechanisms and Functional Significance of Peripheral and Central Entrainment by Respiration. *World Journal of Neuroscience*, *8*, 480-500. <https://doi.org/10.4236/wjns.2018.84038>
- Jerath, R., & Beveridge, C. (2020). Respiratory Rhythm, Autonomic Modulation, and the Spectrum of Emotions: The Future of Emotion Recognition and Modulation. *Frontiers in Psychology*, *11*, Article No. 1980. <https://doi.org/10.3389/fpsyg.2020.01980>
- Jerath, R., & Crawford, M. W. (2015). How Does the Body Affect the Mind? Role of Cardiorespiratory Coherence in the Spectrum of Emotions. *Advances in Mind-Body Medicine*, *29*, 4.
- Jerath, R., Beveridge, C., & Jensen, M. (2019). On the Hierarchical Organization of Oscillatory Assemblies: Layered Superimposition and a Global Bioelectric Framework. *Frontiers in Human Neuroscience*, *13*, Article No. 426. <https://doi.org/10.3389/fnhum.2019.00426>
- Kim, D., Lee, K., Kim, J., Whang, M., & Kang, S. W. (2013). Dynamic Correlations between Heart and Brain Rhythm during Autogenic Meditation. *Frontiers in Human Neuroscience*, *7*, Article No. 414. <https://doi.org/10.3389/fnhum.2013.00414>

- Kuo, C. S., Darmanis, S., Diaz de Arce, A., Liu, Y., Almanzar, N., Wu, T. T. et al. (2022). Neuroendocrinology of the Lung Revealed by Single-Cell RNA Sequencing. *eLife*, *11*, e78216. <https://doi.org/10.7554/elife.78216>
- Law, C. S. H., & Leung, L. S. (2018). Long-Term Potentiation and Excitability in the Hippocampus Are Modulated Differently by  $\Theta$  Rhythm. *eNeuro*, *5*, ENEURO.0236-18.2018. <https://doi.org/10.1523/eneuro.0236-18.2018>
- Lee, Y., Ryu, Y., Jung, W., Kim, J., Lee, T., & Chae, Y. (2017). Understanding Mind-Body Interaction from the Perspective of East Asian Medicine. *Evidence-Based Complementary and Alternative Medicine*, *2017*, Article ID: 7618419. <https://doi.org/10.1155/2017/7618419>
- Leung, L. S., & Law, C. S. H. (2020). Phasic Modulation of Hippocampal Synaptic Plasticity by Theta Rhythm. *Behavioral Neuroscience*, *134*, 595-612. <https://doi.org/10.1037/bne0000354>
- Lisman, J. (2015). The Challenge of Understanding the Brain: Where We Stand in 2015. *Neuron*, *86*, 864-882. <https://doi.org/10.1016/j.neuron.2015.03.032>
- Maric, V., Ramanathan, D., & Mishra, J. (2020). Respiratory Regulation & Interactions with Neuro-Cognitive Circuitry. *Neuroscience & Biobehavioral Reviews*, *112*, 95-106. <https://doi.org/10.1016/j.neubiorev.2020.02.001>
- Martinek, R., Ladrova, M., Sidikova, M., Jaros, R., Behbehani, K., Kahankova, R. et al. (2021). Advanced Bioelectrical Signal Processing Methods: Past, Present and Future Approach—Part I: Cardiac Signals. *Sensors*, *21*, Article No. 5186. <https://doi.org/10.3390/s21155186>
- Noble, D. J., & Hochman, S. (2019). Hypothesis: Pulmonary Afferent Activity Patterns during Slow, Deep Breathing Contribute to the Neural Induction of Physiological Relaxation. *Frontiers in Physiology*, *10*, Article No. 1176. <https://doi.org/10.3389/fphys.2019.01176>
- Ojeda Valencia, G., Gregg, N. M., Huang, H., Lundstrom, B. N., Brinkmann, B. H., Pal Attia, T. et al. (2023). Signatures of Electrical Stimulation Driven Network Interactions in the Human Limbic System. *The Journal of Neuroscience*, *43*, 6697-6711. <https://doi.org/10.1523/jneurosci.2201-22.2023>
- Oku, Y. (2022). Temporal Variations in the Pattern of Breathing: Techniques, Sources, and Applications to Translational Sciences. *The Journal of Physiological Sciences*, *72*, Article No. 22. <https://doi.org/10.1186/s12576-022-00847-z>
- Owens, M. T., & Tanner, K. D. (2017). Teaching as Brain Changing: Exploring Connections between Neuroscience and Innovative Teaching. *CBE—Life Sciences Education*, *16*, fe2. <https://doi.org/10.1187/cbe.17-01-0005>
- Pace-Schott, E. F., Amole, M. C., Aue, T., Balconi, M., Bylsma, L. M., Critchley, H. et al. (2019). Physiological Feelings. *Neuroscience & Biobehavioral Reviews*, *103*, 267-304. <https://doi.org/10.1016/j.neubiorev.2019.05.002>
- Rolls, E. T. (2019). The Cingulate Cortex and Limbic Systems for Action, Emotion, and Memory. In *Handbook of Clinical Neurology* (pp. 23-37). Elsevier. <https://doi.org/10.1016/b978-0-444-64196-0.00002-9>
- Russo, M. A., Santarelli, D. M., & O'Rourke, D. (2017). The Physiological Effects of Slow Breathing in the Healthy Human. *Breathe*, *13*, 298-309. <https://doi.org/10.1183/20734735.009817>
- Schnorbusch, K., Lembrechts, R., Pintelon, I., Timmermans, J., Brouns, I., & Adriaensen, D. (2013). Gabaergic Signaling in the Pulmonary Neuroepithelial Body Microenvironment: Functional Imaging in GAD67-GFP Mice. *Histochemistry and Cell Biology*, *140*, 549-566. <https://doi.org/10.1007/s00418-013-1093-x>

- Trost, W., & Vuilleumier, P. (2013). Rhythmic Entrainment as a Mechanism for Emotion Induction by Music. In T. Cochrane, *et al.* (Eds.), *The Emotional Power of Music: Multidisciplinary Perspectives on Musical Arousal, Expression, and Social Control* (pp. 213-225). Oxford University Press.  
<https://doi.org/10.1093/acprof:oso/9780199654888.003.0016>
- Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A. S. (2017). The Influences of Emotion on Learning and Memory. *Frontiers in Psychology*, *8*, Article No. 1454.  
<https://doi.org/10.3389/fpsyg.2017.01454>
- Valentinuzzi, M. E. (2007). Bioelectrical Signal Processing in Cardiac and Neurological Applications and Electromyography: Physiology, Engineering, and Noninvasive Applications. *BioMedical Engineering OnLine*, *6*, Article No. 27.  
<https://doi.org/10.1186/1475-925x-6-27>
- Vidotto, L. S., Bigliassi, M., Jones, M. O., Harvey, A., & Carvalho, C. R. F. (2018). Stop Thinking! I Can't! Do Attentional Mechanisms Underlie Primary Dysfunctional Breathing? *Frontiers in Physiology*, *9*, Article No. 782.  
<https://doi.org/10.3389/fphys.2018.00782>
- Vidotto, L. S., Carvalho, C. R. F. d., Harvey, A., & Jones, M. (2019). Dysfunctional Breathing: What Do We Know? *Jornal Brasileiro de Pneumologia*, *45*, e20170347.  
<https://doi.org/10.1590/1806-3713/e20170347>
- Von Leupoldt, A., Vovk, A., Bradley, M. M., Keil, A., Lang, P. J., & Davenport, P. W. (2010). The Impact of Emotion on Respiratory-Related Evoked Potentials. *Psychophysiology*, *47*, 579-586. <https://doi.org/10.1111/j.1469-8986.2009.00956.x>
- Weng, H. Y., Feldman, J. L., Leggio, L., Napadow, V., Park, J., & Price, C. J. (2021). Interventions and Manipulations of Interoception. *Trends in Neurosciences*, *44*, 52-62.  
<https://doi.org/10.1016/j.tins.2020.09.010>
- Wolff, M., Morceau, S., Folkard, R., Martin-Cortecero, J., & Groh, A. (2021). A Thalamic Bridge from Sensory Perception to Cognition. *Neuroscience & Biobehavioral Reviews*, *120*, 222-235. <https://doi.org/10.1016/j.neubiorev.2020.11.013>
- Zaccaro, A., Perrucci, M. G., Parrotta, E., Costantini, M., & Ferri, F. (2022). Brain-Heart Interactions Are Modulated across the Respiratory Cycle via Interoceptive Attention. *NeuroImage*, *262*, Article ID: 119548. <https://doi.org/10.1016/j.neuroimage.2022.119548>
- Zaccaro, A., Piarulli, A., Laurino, M., Garbella, E., Menicucci, D., Neri, B. et al. (2018). How Breath-Control Can Change Your Life: A Systematic Review on Psycho-Physiological Correlates of Slow Breathing. *Frontiers in Human Neuroscience*, *12*, Article No. 353.  
<https://doi.org/10.3389/fnhum.2018.00353>
- Zelano, C., Jiang, H., Zhou, G., Arora, N., Schuele, S., Rosenow, J. et al. (2016). Nasal Respiration Entrain Human Limbic Oscillations and Modulates Cognitive Function. *The Journal of Neuroscience*, *36*, 12448-12467.  
<https://doi.org/10.1523/jneurosci.2586-16.2016>