Breathing Bibliography

Elia Vecchione, PhD
Leonard Vecchione, MA
Michael VanDenBergh, MA
Julie Ballschneider, BS

Table of Contents

General

Jerath, R., Edry, J. W., Barnes, V. A., & Jerath, V. (2006). Physiology of long pranaymic breathing: Neural respiratory elements may provide a mechanism that explains how slow deep breathing shifts the autonomic nervous system. *Medical Hypotheses, 67*(3), 566-571.

Pranayamic breathing, defined as a manipulation of breath movement, has been shown to contribute to a physiologic response characterized by the presence of decreased oxygen consumption, decreased heart rate, and decreased blood pressure, as well as increased theta wave amplitude in EEG recordings, increased parasympathetic activity accompanied by the experience of alertness and reinvigoration. The mechanism of how pranayamic breathing interacts with the nervous system affecting metabolism and autonomic functions remains to be clearly understood. It is our hypothesis that voluntary slow deep breathing functionally resets the autonomic nervous system through stretch-induced inhibitory signals and hyperpolarization currents propagated through both neural and non-neural tissue which synchronizes neural elements in the heart, lungs, limbic system and cortex. During inspiration, stretching of lung tissue produces inhibitory signals by action of slowly adapting stretch receptors (SARs) and hyperpolarization current by action of fibroblasts. Both inhibitory impulses and hyperpolarization current are known to synchronize neural elements leading to the modulation of the nervous system and decreased metabolic activity indicative of the parasympathetic state. In this paper we propose pranayama's physiologic mechanism through a cellular and systems level perspective, involving both neural and non-neural elements. This theoretical description describes a common physiological mechanism underlying pranayama and elucidate the role of the respiratory and cardiovascular system on modulating the autonomic nervous system. Along with facilitating the design of clinical breathing techniques for the treatment of autonomic nervous system and other disorders, this model will also validate pranayama as a topic requiring more research.

Lehrer, P. M., & Gervitz, R. (2014). Heart rate variability biofeedback: how and why does it work? *Frontiers in Psychology, 5*, 756.

In recent years there has been substantial support for heart rate variability biofeedback (HRVB) as a treatment for a variety of disorders and for performance enhancement (Gevirtz, 2013). Since conditions as widely varied as asthma and depression seem to respond to this form of cardiorespiratory feedback training, the issue of possible mechanisms becomes more salient. The most supported possible mechanism is the strengthening of homeostasis in the baroreceptor (Vaschillo et al., 2002; Lehrer et al., 2003). Recently, the effect on the vagal afferent pathway to the frontal cortical areas has been proposed. In this article, we review these and other possible mechanisms that might explain the positive effects of HRVB.

Mason, H., Vandoni, M., deBarbieri, G., Codrons, E., Ugargol, V., & Bernardi, L. (2013). Cardiovascular and Respiratory Effect of Yogic Slow Breathing in the Yoga

Beginner: What Is the Best Approach? *Evidence-Based Complementary and Alternative Medicine, 2013*, Article ID 743504.

Slow breathing increases cardiac-vagal baroreflex sensitivity (BRS), improves oxygen saturation, lowers blood pressure, and reduces anxiety. Within the yoga tradition slow breathing is often paired with a contraction of the glottis muscles. This resistance breath "ujjayi" is performed at various rates and ratios of inspiration/expiration. To test whether ujjayi had additional positive effects to slow breathing, we compared BRS and ventilatory control under different breathing patterns (equal/unequal inspiration/expiration at 6 breath/min, with/without ujjayi), in 17 yoga-naive young healthy participants. BRS increased with slow breathing techniques with or without expiratory ujjayi ($P < 0.05$ or higher) except with inspiratory + expiratory ujjayi. The maximal increase in BRS and decrease in blood pressure were found in slow breathing with equal inspiration and expiration. This corresponded with a significant improvement in oxygen saturation without increase in heart rate and ventilation. Ujjayi showed similar increase in oxygen saturation but slightly lesser improvement in baroreflex sensitivity with no change in blood pressure. The slow breathing with equal inspiration and expiration seems the best technique for improving baroreflex sensitivity in yoga-naive subjects. The effects of ujjayi seems dependent on increased intrathoracic pressure that requires greater effort than normal slow breathing.

Sroufe, L. A. (1971). Effects of depth and rate of breathing on heart rate and heart rate variability. *Psychophysiology, 8*(5), 648-655.

Effects of depth and rate of breathing on heart rate (HR) and HR variability were observed in two experiments. Respiration rate (RR) affected only cardiac stability, faster breathing producing more stable cardiac rate. Respiration depth (RD) affected both HR level and variability. Deep breathing produced faster, more variable HR, while shallow breathing had the opposite effects. A third experiment, in which Ss were trained to control HR using respiration, further illustrated the dramatic effects of respiration on cardiac rate. Implications of these results for experiments utilizing HR as a dependent variable and studies of autonomic control were discussed.

Widdicombe, J. G., & Sterling, G. M. (1970). The Autonomic Nervous System and Breathing. *The Journal of the American Medical Association, 126*(2), 311-329.

The role of the autonomic nervous system in the control of lung ventilation and gas exchange can be considered in two ways. The first is the analysis of primary control mechanisms involving, for example, specific groups of receptors and their afferent nerves in the autonomic nervous system and their reflex action on breathing or on lung effector tissues. This analytical approach has been used extensively in studies with experimental animals, in which it is possible to isolate single components of the control mechanisms and to determine their properties. These studies lead to clear, forthright, and usually reliable statements such as the following: stimulation of pulmonary stretch receptors inhibits breathing and causes bronchodilation; hypoxia has a direct constrictor action on the pulmonary vascular bed; and stimulation of tracheal irritant receptors causes coughing, bronchoconstriction, and hypertension.

Yackle, K., Schwarz, L. A., Kam, K., Sorokin, J. M., Huguenard, J. R., Feldman, J. L., Luo, L., & Krasnow, M. A. (2017). Breathing control center neurons that promote arousal in mice. *Science*, *355*(6332), 1411-1415.

Slow, controlled breathing has been used for centuries to promote mental calming, and it is used clinically to suppress excessive arousal such as panic attacks. However, the physiological and neural basis of the relationship between breathing and higher-order brain activity is unknown. We found a neuronal subpopulation in the mouse preBötzinger complex (preBötC), the primary breathing rhythm generator, which regulates the balance between calm and arousal behaviors. Conditional, bilateral genetic ablation of the ~175 Cdh9/Dbx1 double-positive preBötC neurons in adult mice left breathing intact but increased calm behaviors and decreased time in aroused states. These neurons project to, synapse on, and positively regulate noradrenergic neurons in the locus coeruleus, a brain center implicated in attention, arousal, and panic that projects throughout the brain.

Zelano, C., Jiang, H., Zhou, G., Arora, N., Schuele, S., Rosenow, J., & Gottfried, J. A. (2016). Nasal Respiration Entrains Human Limbic Oscillations and Modulates Cognitive Function. *Journal of Neuroscience*, *36*(49), 12448-12467.

The need to breathe links the mammalian olfactory system inextricably to the respiratory rhythms that draw air through the nose. In rodents and other small animals, slow oscillations of local field potential activity are driven at the rate of breathing (~2–12 Hz) in olfactory bulb and cortex, and faster oscillatory bursts are coupled to specific phases of the respiratory cycle. These dynamic rhythms are thought to regulate cortical excitability and coordinate network interactions, helping to shape olfactory coding, memory, and behavior. However, while respiratory oscillations are a ubiquitous hallmark of olfactory system function in animals, direct evidence for such patterns is lacking in humans. In this study, we acquired intracranial EEG data from rare patients (Ps) with medically refractory epilepsy, enabling us to test the hypothesis that cortical oscillatory activity would be entrained to the human respiratory cycle, albeit at the much slower rhythm of ~0.16–0.33 Hz. Our results reveal that natural breathing synchronizes electrical activity in human piriform (olfactory) cortex, as well as in limbic-related brain areas, including amygdala and hippocampus. Notably, oscillatory power peaked during inspiration and dissipated when breathing was diverted from nose to mouth. Parallel behavioral experiments showed that breathing phase enhances fear discrimination and memory retrieval. Our findings provide a unique framework for understanding the pivotal role of nasal breathing in coordinating neuronal oscillations to support stimulus processing and behavior.

Stress

Bernardi, L., Wdowczyk-Szulc, J., Valenti, C., Castoldi, S., Passino, C., Spadacini, G., & Sleight, P. (2000). Effects of controlled breathing, mental activity and mental stress with or without verbalization on heart rate variability. *Journal of the American College of Cardiology, 35*(6), 1462-1469.

To assess whether talking or reading (silently or aloud) could affect heart rate variability (HRV) and to what extent these changes require a simultaneous recording of respiratory activity to be correctly interpreted. Sympathetic predominance in the power spectrum obtained from short- and long-term HRV recordings predicts a poor prognosis in a number of cardiac diseases. Heart rate variability is often recorded without measuring respiration; slow breaths might artefactually increase low frequency power in RR interval (RR) and falsely mimic sympathetic activation. In 12 healthy volunteers we evaluated the effect of free talking and reading, silently and aloud, on respiration, RR and blood pressure (BP). We also compared spontaneous breathing to controlled breathing and mental arithmetic, silent or aloud. The power in the so called low- (LF) and high-frequency (HF) bands in RR and BP was obtained from autoregressive power spectrum analysis. Compared with spontaneous breathing, reading silently increased the speed of breathing ($p < 0.05$), decreased mean RR and RR variability and increased BP. Reading aloud, free talking and mental arithmetic aloud shifted the respiratory frequency into the LF band, thus increasing LF% and decreasing HF% to a similar degree in both RR and respiration, with decrease in mean RR but with minor differences in crude RR variability. Simple mental and verbal activities markedly affect HRV through changes in respiratory frequency. This possibility should be taken into account when analyzing HRV without simultaneous acquisition and analysis of respiration.

Brown, R. P., Gerbarg, P. L. (2005). Sudarshan Kriya Yogic Breathing in the Treatment of Stress, Anxiety, and Depression: Part I—Neurophysiology. *The Journal of Alternative and Complementary Medicine, 11*(1), 189-201.

Mind–body interventions are beneficial in stress-related mental and physical disorders. Current research is finding associations between emotional disorders and vagal tone as indicated by heart rate variability. Yogic breathing is a unique method for balancing the autonomic nervous system and influencing psychologic and stress-related disorders. Many studies demonstrate effects of yogic breathing on brain function and physiologic parameters. Sudarshan Kriya yoga (SKY), a sequence of specific breathing techniques can alleviate anxiety, depression, everyday stress, post-traumatic stress, and stress-related medical illnesses. Mechanisms contributing to a state of calm alertness include increased parasympathetic drive, calming of stress response systems, neuroendocrine release of hormones, and thalamic generators.

Cappo, B. M., & Holmes, D. S. (1984). The utility of prolonged respiratory exhalation for reducing physiological and psychological arousal in non-threatening and threatening situations. *Journal of Psychosomatic Research, 28*(4), 265-273.

To determine whether slowing and altering the respiratory pattern is an effective means for reducing physiological and psychological arousal, subjects participated in one of three treatment conditions in which they reduced their respiration rate to 6 cpm and either inhaled quickly and exhaled slowly, inhaled slowly and exhaled quickly, or spent equal amounts of time inhaling and exhaling. Other subjects participated in a distraction control condition or in a no-treatment control condition. Arousal was measured during a practice period, a threat (electric shocks) anticipation period, and a threat confrontation period. The results indicated that the breathing manipulations were not effective in reducing arousal during the practice period, but that inhaling quickly and exhaling slowly was consistently effective for reducing physiological (skin resistance) and psychological (subjective cognitive) arousal during the anticipation and confrontation periods.

Ma, X., Yue, Z., Gong, Z., Zhang, H., Duan, N., Shi, Y., Wei, G., & Li, Y. (2017). The Effect of Diaphragmatic Breathing on Attention, Negative Affect and Stress in Healthy Adults. *Frontiers in Psychology*, *8*, 874.

A growing number of empirical studies have revealed that diaphragmatic breathing may trigger body relaxation responses and benefit both physical and mental health. However, the specific benefits of diaphragmatic breathing on mental health remain largely unknown. The present study aimed to investigate the effect of diaphragmatic breathing on cognition, affect, and cortisol responses to stress. Forty participants were randomly assigned to either a breathing intervention group (BIG) or a control group (CG). The BIG received intensive training for 20 sessions, implemented over 8 weeks, employing a real-time feedback device, and an average respiratory rate of 4 breaths/min, while the CG did not receive this treatment. All participants completed pre- and post-tests of sustained attention and affect. Additionally, pre-test and post-test salivary cortisol concentrations were determined in both groups. The findings suggested that the BIG showed a significant decrease in negative affect after intervention, compared to baseline. In the diaphragmatic breathing condition, there was a significant interaction effect of group by time on sustained attention, whereby the BIG showed significantly increased sustained attention after training, compared to baseline. There was a significant interaction effect of group and time in the diaphragmatic breathing condition on cortisol levels, whereby the BIG had a significantly lower cortisol level after training, while the CG showed no significant change in cortisol levels. In conclusion, diaphragmatic breathing could improve sustained attention, affect, and cortisol levels. This study provided evidence demonstrating the effect of diaphragmatic breathing, a mind-body practice, on mental function, from a health psychology approach, which has important implications for health promotion in healthy individuals.

Martarelli, D., Cocchioni, M., Scuri, S., & Pompei, P. (2011). Diaphragmatic breathing reduces exercise-induced oxidative stress. *Evidence-Based Complementary and Alternative Medicine*, *17*(7), 623-628.

Diaphragmatic breathing is relaxing and therapeutic, reduces stress, and is a fundamental procedure of Pranayama Yoga, Zen, transcendental meditation and other meditation practices. Analysis of oxidative stress levels in people who meditate indicated that meditation correlates with lower oxidative stress levels, lower cortisol levels and higher melatonin levels. It is known that cortisol inhibits enzymes responsible for the antioxidant activity of cells and that melatonin is a

strong antioxidant; therefore, in this study, we investigated the effects of diaphragmatic breathing on exercise-induced oxidative stress and the putative role of cortisol and melatonin hormones in this stress pathway. We monitored 16 athletes during an exhaustive training session. After the exercise, athletes were divided in two equivalent groups of eight subjects. Subjects of the studied group spent 1 h relaxing performing diaphragmatic breathing and concentrating on their breath in a quiet place. The other eight subjects, representing the control group, spent the same time sitting in an equivalent quite place. Results demonstrate that relaxation induced by diaphragmatic breathing increases the antioxidant defense status in athletes after exhaustive exercise. These effects correlate with the concomitant decrease in cortisol and the increase in melatonin. The consequence is a lower level of oxidative stress, which suggests that an appropriate diaphragmatic breathing could protect athletes from long-term adverse effects of free radicals.

Anxiety

Kim, S. D., & Kim, H. S. (2005). Effects of a relaxation breathing exercise on anxiety, depression, and leukocyte in hemopoietic stem cell transplantation patients. *Cancer Nursing*, *28*(1), 79-83.

This study was performed to investigate the effects of a relaxation breathing exercise on anxiety, depression, and leukocyte count in patients who underwent allogenic hemopoietic stem cell transplantation. Thirty-five patients were randomly selected, with 18 assigned to an exercise group and 17 assigned to a control group. The exercise intervention was applied to the exercise group for 30 minutes every day for 6 weeks. It consisted of physical exercises combined with relaxation breathing. Anxiety was measured by the State-Trait Anxiety Inventory and depression was measured by the Beck Depression Inventory. The total number of leukocytes was calculated from total and differential counts of peripheral white blood cells. The exercise group had a greater decrease in anxiety and depression than did the control group, but the total number of leukocytes did not significantly differ between the two groups. These findings indicate that a relaxation breathing exercise would improve anxiety and depression levels in patients who undergo allogenic hemopoietic stem cell transplantation, but would not affect the number of leukocytes.

Psychological Well-Being

Van Den Wittenboer, G., Van Der Wolf, K., Van Dixhoorn, J. (2003). Respiratory Variability and Psychological Well-Being in Schoolchildren. *Behavior Modification*, *27*(5), 653-670.

Among the relations between respiration and psychological state, associations with respiratory variability have been contradictory. In this study, respiration was measured noninvasively in 162 children with a mean age of 11 years (from 9 to 13). They completed a battery of psychological tests. Structural Equation Modeling (SEM or LISREL) revealed a model that fit the data well (X2 = 88.201, df = 79, p = .224). In this model, respiratory variability was positively related to anger-in and negatively to negative fear of failure and neurotic complaints. Respiration rate was positively related to positive fear of failure, and duty cycle was positively related to the latent variable of negative affect. Variability in resting time components of respiration was higher among children with less fear of failure and fewer complaints. Therefore, respiratory variability need not necessarily be a sign of psychological dysfunctions, and interventions should not always impose a fixed breathing pattern.

Pain

Busch, V., Magerl, W., Kern, U., Haas, J., Hajak, G., & Eichhammer, P. (2011). The Effect of Deep and Slow Breathing on Pain Perception, Autonomic Activity, and Mood Processing—An Experimental Study. *Pain Medicine, 13*(2), 215-228.

Deep and slow breathing (DSB) techniques, as a component of various relaxation techniques, have been reported as complementary approaches in the treatment of chronic pain syndromes. In order to disentangle the effects of relaxation and respiration, we investigated two different DSB techniques at the same respiration rates and depths on pain perception, autonomic activity, and mood in 16 healthy subjects. In the attentive DSB intervention, subjects were asked to breathe guided by a respiratory feedback task requiring a high degree of concentration and constant attention. In the relaxing DSB intervention, the subjects relaxed during the breathing training. Our results suggest that the way of breathing decisively influences autonomic and pain processing, thereby identifying DSB in concert with relaxation as the essential feature in the modulation of sympathetic arousal and pain perception. Thermal detection and pain thresholds for cold and hot stimuli and profile of mood states were examined before and after the breathing sessions. The mean detection and pain thresholds showed a significant increase resulting from the relaxing DSB, whereas no significant changes of these thresholds were found associated with the attentive DSB. The mean skin conductance levels indicating sympathetic activity decreased significantly during the relaxing DSB intervention but not during the attentive DSB. Both breathing interventions showed similar reductions in negative feelings (tension, anger, and depression).

Posttraumatic Stress Disorder

Brunet, A., Orr, S. P., Tremblay, J., Robertson, K., Nader, K., & Pitman, R. K. (2008). Effect of post-retrieval propranolol on psychophysiologic responding during subsequent script-driven traumatic imagery in post-traumatic stress disorder. *Journal of Psychiatric Research, 42*(6), 503-506.

The beta-adrenergic blocker propranolol given within hours of a psychologically traumatic event reduces physiologic responses during subsequent mental imagery of the event. Here we tested the effect of propranolol given after the retrieval of memories of past traumatic events. Subjects with chronic post-traumatic stress disorder described their traumatic event during a script preparation session and then received a one-day dose of propranolol (n=9) or placebo (n=10), randomized and double-blind. A week later, they engaged in

script-driven mental imagery of their traumatic event while heart rate, skin conductance, and left corrugator electromyogram were measured. Physiologic responses were significantly smaller in the subjects who had received post-reactivation propranolol a week earlier. Propranolol given after reactivation of the memory of a past traumatic event reduces physiologic responding during subsequent mental imagery of the event in a similar manner to propranolol given shortly after the occurrence of a traumatic event.

Kim, S. H., Schneider, S. M., Bevans, M., Kravitz, L., Mermier, C., Qualls, C., & Burge, M. R. (2013). PTSD Symptom Reduction With Mindfulness-Based Stretching and Deep Breathing Exercise: Randomized Controlled Clinical Trial of Efficacy. *The Journal of Clinical Endocrinology and Metabolism, 98*(7), 2984-2992.

Abnormal cortisol levels are a key pathophysiological indicator of post-traumatic stress disorder (PTSD). Endogenous normalization of cortisol concentration through exercise may be associated with PTSD symptom reduction. The aim of the study was to determine whether mindfulness-based stretching and deep breathing exercise (MBX) normalizes cortisol levels and reduces PTSD symptom severity among individuals with subclinical features of PTSD. A randomized controlled trial was conducted at the University of New Mexico Health Sciences Center. Twenty-nine nurses (28 female) aged 45–66 years participated in the study. Sixty-minute MBX sessions were conducted semiweekly for 8 weeks. Serum cortisol was measured, and the PTSD Checklist–Civilian version (PCL-C) was performed at baseline and weeks 4, 8, and 16. Twenty-nine participants completed the study procedures, 22 (79%) with PTSD symptoms (MBX, n = 11; control, n = 11), and 7 (21%) without PTSD (BASE group). Eight-week outcomes for the MBX group were superior to those for the control group (mean difference for PCL-C scores, −13.6; 95% confidence interval [CI], −25.6, −1.6; P = .01; mean difference for serum cortisol, 5.8; 95% CI, 0.83, 10.8; P = .01). No significant differences were identified between groups in any other items. The changes in the MBX group were maintained at the 16-week follow-up (P = .85 for PCL-C; P = .21 for cortisol). Our data show that improved PTSD scores were associated with normalization of cortisol levels (P < .05). The results suggest that MBX appears to reduce the prevalence of PTSD-like symptoms in individuals exhibiting subclinical features of PTSD.

Poundja, J., Sanche, S., Tremblay, J., & Brunet, A. (2012). Trauma reactivation under the influence of propranolol: an examination of clinical predictors. *European Journal of Psychotraumatology*, *3*.

BACKGROUND: In two recent studies conducted by our group, a treatment combining propranolol with a brief reactivation session subsequently reduced posttraumatic stress disorder (PTSD) symptom severity and diagnosis, as well as reducing psychophysiological responses during trauma-related script-driven imagery. One likely explanation for those results is that memory reconsolidation was blocked by propranolol. OBJECTIVE: We explored the influence of various predictors on treatment outcome (i.e., PTSD severity), and whether the treated individuals improved in other important domains of functioning associated with PTSD. METHOD: Thirty-three patients with longstanding PTSD participated in a

6-week open-label trial consisting of actively recalling one's trauma under the influence of propranolol, once a week. RESULTS: Treated patients reported a better quality of life, less comorbid depressive symptoms, less negative emotions in their daily life and during trauma recollections. Women were also found to improve more than men. Type of trauma (childhood vs. adulthood), time elapsed since trauma, borderline personality traits, depressive symptoms severity, Axis I comorbidity, and age did not influence treatment outcome. CONCLUSION: These results must await publication of a randomized-controlled trial to further delineate effectiveness with this novel treatment approach.

Seppala, E. M., Nitschke, J. B., Tudorascu, D. L., Hayes, A., Goldstein, M. R., Nguyen, D. T. H., Perlman, D., & Davidson, R. J. (2014). Breathing-Based Meditation Decreases Posttraumatic Stress Disorder Symptoms in U.S. Military Veterans: A Randomized Controlled Longitudinal Study, *Journal of Traumatic Stress*, *27*(4), 397-405.

Given the limited success of conventional treatments for veterans with posttraumatic stress disorder (PTSD), investigations of alternative approaches are warranted. We examined the effects of a breathing-based meditation intervention, Sudarshan Kriya yoga, on PTSD outcome variables in U.S. male veterans of the Iraq or Afghanistan war. We randomly assigned 21 veterans to an active ($n = 11$) or waitlist control ($n = 10$) group. Laboratory measures of eye-blink startle and respiration rate were obtained before and after the intervention, as were self-report symptom measures; the latter were also obtained 1 month and 1 year later. The active group showed reductions in PTSD scores, $d = 1.16$, 95% CI [0.20, 2.04], anxiety symptoms, and respiration rate, but the control group did not. Reductions in startle correlated with reductions in hyperarousal symptoms immediately postintervention ($r =. 93$, $p <. 001$) and at 1-year follow-up ($r =. 77$, $p =. 025$). This longitudinal intervention study suggests there may be clinical utility for Sudarshan Kriya yoga for PTSD.

Addiction and Substance Abuse

McClernon, F. J., Westman, E. C., & Rose, J. E. (2004). The effects of controlled deep breathing on smoking withdrawal symptoms in dependent smokers. *Addictive Behaviors, 29*(4), 765-772.

This study was designed to assess the effect of controlled deep breathing on smoking withdrawal symptoms. In two laboratory sessions, dependent smokers refrained from smoking for 4 h. During a deep breathing session, participants were instructed to take a series of deep breaths every 30 min. During a control session, participants sat quietly. Controlled deep breathing significantly reduced smoking withdrawal symptoms, including craving for cigarettes and negative affect (tense, irritable), while resulting in the maintenance of baseline arousal (wide awake, able to concentrate) levels. Furthermore, a history of heavy smoking was associated with greater increases in arousal during the deep breathing session. The results of this preliminary study suggest that controlled deep breathing may be useful for relieving symptoms of smoking withdrawal.