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SPECIAL ISSUE

Balancing Unbalanced Breathing: The Clinical Use of Capnographic Biofeedback

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Dysfunctional breathing, primarily in the form of overbreathing or hyperventilation, has been reported to play a major role for some individuals with anxiety and panic disorders. This is due to the decrease in carbon dioxide, a state called hypocapnia, which results from hyperventilation. The author reviews the physiological effects of hypocapnia and describes how carbon dioxide levels are measured with capnography. In addition, she introduces the use of capnography as a form of biofeedback and outlines ways to incorporate capnography into a clinical setting. Capnographic biofeedback enables individuals to become aware of the impact dysfunctional breathing has on their symptoms and assists them in learning more balanced, healthy breathing patterns. Use of this type of biofeedback training has been found to decrease panic symptoms and may be useful in improving physiological functioning in other medical and psychiatric disorders as well.

Breathing is undeniably critical in maintaining life. The body can sustain life for days without water, weeks without food, but only minutes without breath. But breathing is more than just about sustaining life; it should also be flexible enough to meet the changing demands of living. All too often due to medical and psychological reasons, breathing can become stuck in unhealthy, rigid patterns. Unfortunately, these dysfunctional patterns can have a wide range of negative effects, affecting numerous aspects of bodily functioning and resulting in a number of undesirable symptoms. Fortunately, learning to regulate the breath, with the assistance of biofeedback, can establish more healthy patterns, which can have a wide range of positive effects, promoting health and decreasing psychological symptoms.

Physiology of Breathing

At the most basic level, breathing is about the exchange of gases. During inhalation, oxygen (O_2) is taken into the body. It enters the blood and circulates throughout the body, where it is consumed by tissues and organs and carbon dioxide (CO_2) is produced as a by-product of this cellular metabolism. In one sense, CO_2 can be thought of as the body's exhaust, but this gas is far more than just exhaust, waste, or a by-product that needs to be expelled from the body. In fact, CO_2 is just as important and necessary in maintaining life as O_2. It is CO_2 that is responsible for distributing O_2 to the tissues and organs, maintaining a balanced pH of the blood and bodily fluids, and maintaining proper balance of electrolytes (Courtney, 2009; Khazan, 2013; Litchfield, 2003).

Under optimal conditions, the amount of oxygen consumed through breathing meets the metabolic demands at the moment, and appropriate levels of CO_2 are produced and expelled, thereby maintaining the body's delicate chemical balance. This is the case when the body is at rest, as well as during periods of intense physical activity, such as exercise. During these periods of physical activity, breathing is increased to take in greater amounts of oxygen in order to meet the greater metabolic demands, producing and expelling large amounts of CO_2, but the delicate chemical balance is still maintained. Problems arise when breathing becomes unbalanced and dysfunctional.

Dysfunctional Breathing

Dysfunctional breathing can be defined as breathing that is inappropriate or inefficient in meeting the body's metabolic needs and environmental conditions at a given point in time (Courtney, 2009). As summarized by Courtney (2009), the prevalence of dysfunctional breathing in the general population is estimated to be 5% to 11%. The prevalence increases in asthmatics to 30% and is as high as 83% in those with anxiety disorders.

The most common pattern of dysfunctional breathing is overbreathing (also referred to as hyperventilation), which is defined as breathing in excess of current metabolic needs typically due to a rapid rate of respiration and/or inhaling large amounts of air (tidal volume), which is a common behavioral response to daily environmental, emotional, cognitive, and social challenges (Litchfield, 2003; Schwartz, 1995). This pattern of breathing is unhealthy because it results in a deficit of CO_2 (hypocapnia) due to breathing out greater amounts of CO_2 than is produced, which can occur fairly quickly due to CO_2's high solubility and ease of elimination, resulting in a broad spectrum of physiological effects (Courtney, 2009). One effect of decreased CO_2 is an increase in blood pH levels, which inhibits hemoglobin from releasing O_2, resulting in a lack of necessary oxygen being delivered to the organs, including the brain. There is a 30% to 40% reduction in O_2 delivered to the brain with moderate overbreathing and up to a 60% reduction with severe overbreathing (Bednarczyk et al., 1990; Khazan, 2013; Litchfield, 2003). Changes in pH levels also disrupt the balance of electrolytes (calcium, sodium, potassium, and magnesium). These chemicals are important in muscle function and the function of neurons with imbalances, resulting in muscular spasms, weakness, and fatigue as well as increased neuronal excitability (Gilbert, 2005; Khazan, 2013). Animal research has correlated hypocapnia in newborn rats with an increased burst rate of the amygdala complex, providing a possible neural mechanism between hyperventilation and feelings of anxiety (Fujii, Onimaru, Suganuma, & Homma, 2010).

Effects of Hypocapnia

Given the wide range of physiological effects, it is understandable why numerous symptoms are associated with hypocapnia. In the short run with a brief episode of overbreathing, sometimes in as little as 1 minute, numerous symptoms can be experienced, including but not limited to muscle tension, sweating, trembling, asthma-type symptoms, shortness of breath, racing heart, headache, chest pain, blurred vision, dizziness, dry mouth, and nausea (Khazan, 2013; Schwartz, 1995). Once this episode has passed and breathing has stabilized, no long-term effects will likely result. The problem results when this episodic response becomes a chronic pattern of breathing. When an individual breathes too much air, far too often, with no increase in metabolic demand, it results in chronically altered levels of CO_2 and more serious symptoms. Chronic overbreathing can contribute to or exacerbate numerous psychological and medical disorders, including but not limited to panic disorder, irritable bowel syndrome, attention deficits, generalized anxiety disorder, sleep apnea, epilepsy, hypertension, and asthma (Khazan, 2013; Schwartz, 1995).

Unfortunately, dysfunctional breathing often goes unrecognized, with the symptoms associated with hypocapnia being attributed to a disease process, to anxiety and stress, or to unknown mysterious reasons, rather than being recognized as an effect of maladaptive breathing. Because overbreathing does not have to necessarily be excessively fast or dramatic, which is a fairly typical misunderstanding of hyperventilation, individuals may not even be aware their breathing is dysfunctional. In addition, because of a lack of awareness and myths regarding proper breathing, when breath training is incorporated into treatment, at least 50% of professionals use instructions ("take a deep breath") or techniques that may induce overbreathing, thereby exacerbating the problem (Litchfield, 2003). Numerous biofeedback devices exist to assist in breath training, including nasal-air-flow temperature sensors, strain gauges, surface electromyography from associated muscles, the incentive inspirometer, and oximetry, to name a few (Schwartz, 1995). Although many of these can be beneficial in helping the client learn the correct mechanics of breathing (proper muscle tension or greater movement of the diaphragm), and a trained and astute clinician can observe aspects of breathing, only capnography can measure CO_2 levels.

Measuring CO_2 with Capnography

Capnography has traditionally been used by anesthesiologists and prehospital emergency medical personnel due to its ability to provide information regarding circulation, ventilation, and metabolism (Brandt, 2010). Through the use of a capnometer, moment-by-moment information on CO_2 levels and respiration rates are provided by numeric values and a waveform. The numeric values represent the end-tidal CO_2 levels measured in mm Hg (millimeters of mercury) or Torr. End-tidal CO_2 refers to the exhaled CO_2 at the end of the breath cycle; the capnometer samples exhaled CO_2 with sampling tube(s) inserted in one or both nostrils. The healthy range for end-tidal CO_2 is between 35 mm Hg and 45 mm Hg. Values less than 35 mm Hg represent various levels of hypocapnia due to overbreathing, with 30 to 35 mm Hg indicating mild to moderate overbreathing, 25 to 30 mm Hg moderate to severe overbreathing, and 25 mm Hg or below severe overbreathing (Khazan, 2013; Wilhelm, Gevirtz, & Roth, 2001).

The waveform generated by the capnometer is also very informative and represents the different phases of exhalation and inhalation. As illustrated in Figure 1, the waveform starts (A-B) at the beginning of the exhalation when no CO_2 is present, represented by the flat baseline. As exhalation continues (B-C), CO_2 levels rapidly rise, reaching a plateau

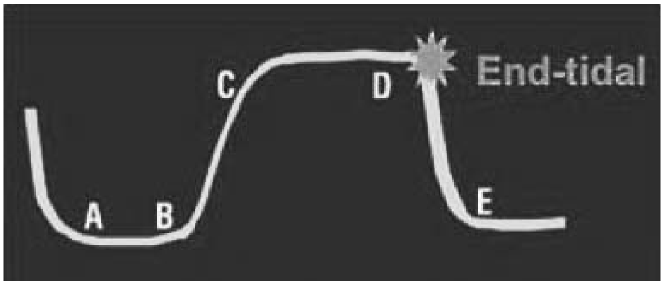

Figure 1. Illustration showing the phases of the capnography waveform (Brandt, 2010).

(C-D) and culminating at the end of the exhalation with the end-tidal CO_2 (D), where CO_2 is at its highest level. During the next inhalation (D-E), CO_2 levels return to baseline (Brandt, 2010). Similar to electroencephalography (EEG), different waveforms can indicate different pathologies; however, for the purposes of this discussion, only an illustration of a hyperventilation waveform is provided. As illustrated in Figure 2, hypocapnia due to hyperventilation often, but not always, produces more waveforms (rapid breaths) with reduced amplitude (less CO_2).

Capnographic Biofeedback

Capnographic Biofeedback and Anxiety

Therefore, during capnographic biofeedback, an individual's end-tidal CO_2 value is fed back to the client, and through breathing instruction and practice, the individual learns to alter this value to a more physiologically healthy range. This technique has largely been investigated with anxiety disorders, particularly panic disorder, with subjects being able to decrease both the frequency and severity of panic attacks as well as symptom complaints as they raised their end-tidal CO_2 values (Meuret, Wilhem, & Roth, 2001). Preliminary evidence suggests this improvement to be fairly substantial, with 40% of subjects reporting no occurrence of panic at the end of a 4-week training period (involving weekly office visits and home training) and 68% being panic free at a 12-month follow-up (Meuret, Wilhem, Ritz, & Roth, 2008). Subjects also reported a 20% to 40% reduction in the fear of panic symptoms as CO_2 values improved (Meuret, Rosenfield, Hofmann, Suvak, & Roth, 2009). However, it has been questioned whether normalizing CO_2 is of importance, as this measure is not always found to correlate precisely with symptoms. Kim, Wollburg, and Roth (2012) demonstrated that whether subjects were taught to raise or lower CO_2 values, the severity of panic disorder was reduced after 1 month of training and held at a 6-month follow-up. The authors hypothesized that the improvement was due to commonalities in the breathing therapies rather than the actual CO_2 level. This is somewhat analogous to slow cortical potential training in neurofeedback, in which subjects are taught to increase and decrease this brain activity to improve self-regulation and

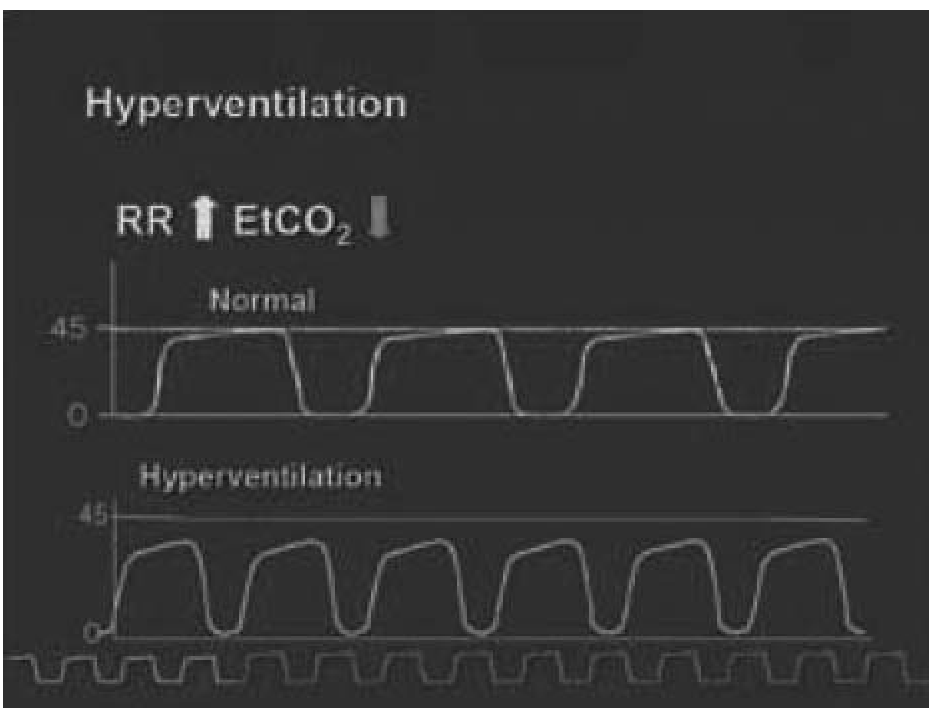

Figure 2. Example of capnography waveform during hyperventilation compared with normal (Brandt, 2010).

gain cortical control. Similarly, the benefit of capnography-assisted breathing training for some individuals may not be the actual CO_2 value at that moment in time but learning to regulate it by changing their breathing, which may have become stuck in dysfunctional patterns.

Capnographic Biofeedback, Medical Disorders, and Other Psychiatric Disorders

Capnographic biofeedback has also been found to effectively decrease symptoms in medical disorders, such as asthma (Ritz, Meuret, Wilhelm, & Roth, 2009), and it seems plausible, although evidence is currently lacking, that this form of biofeedback could be of benefit in other psychiatric disorders as well, particularly due to the effect of hypocapnia on the EEG. In addition to the physiological effects discussed previously, overbreathing also increases slow-wave activity in the EEG (Litchfield, 2003). Increased slow-wave activity is a common abnormal EEG finding in numerous psychiatric disorders. Therefore, capnography biofeedback could be extremely beneficial in cases in which this EEG slowing is due to or exacerbated by overbreathing.

Implementing Capnographic Biofeedback in Clinical Practice

Currently, there is no standard way to implement capnographic biofeedback in clinical practice. The methods used are largely dependent on the clinician's background, education, population served, and access to biofeedback devices (capnometers). Several types of systems and capnometers are available for use in this setting. Some systems, such as the CapnoTrainer®, are more fully integrated biofeedback systems that also incorporate heart rate variability and are likely to be used only within the clinician's office. Other types of portable, handheld capnometers such as the Capnocheck® and the Capnocount mini® also exist and have been found to meet accuracy requirements, although readings can be affected by changing ambient temperatures (Biedler et al., 2003). Although traditionally used in medical settings, these devices could also be used in the context of biofeedback both within the clinician's office and at home, as home training was frequently included in studies and likely is an important component for success. The Capnocount mini® has the added benefit of being able to download the data to a computer for review with the client. as this is an important part of the biofeedback process.

In addition to the variety of biofeedback devices available, there are also a variety of approaches clinicians can use to teach this type of training. However, regardless of the approach, several key components should be included. First and foremost is a breathing assessment that includes questioning the client about his or her breathing, discreetly observing the client's breathing (paying attention to the rate, depth, etc., and evaluating respiratory chemistry with a capnometer). Much like a physiological stress assessment, breathing should be evaluated at rest and during challenge (Khazan, 2013). Education regarding the physiology of breathing and the client's particular patterns of breathing and how this relates to his or her symptoms is also extremely important. The capnometer can also be very helpful with this aspect as the client can be instructed to overbreathe to various degrees as assessed by CO_2 levels and then observe the symptoms that are produced (Khazan, 2013; Litchfield, 2003). In the case of panic attacks, this exercise can be very powerful in demonstrating to clients the role their breathing may be playing in these episodes. In addition, teaching proper mechanics such as slower rate, appropriate depth of breath, rhythmicity, use of the diaphragm and not the chest, and keeping the shoulder muscles relaxed is also a necessary component (Khazan, 2013; Litchfield, 2003). Finally, it is important for both the clinician and the client to keep in mind the goal of this type of breathing training, which is to balance the client's physiology, not induce a particular state. Although many types of breathing patterns exist that can increase momentary alertness or promote relaxation, capnography-assisted breathing is aimed at physiological stabilization by inducing reflexive, brain stem–driven breathing regardless of the context.

Therefore, given the widespread and powerful effect chronic overbreathing can have on numerous aspects of functioning, capnographic biofeedback stands to be a powerful tool. This is particularly true for anxiety and panic disorders, as improvement has been demonstrated with only 4 weeks of training with benefits lasting at least 1 year, but could likely be of benefit in other psychiatric disorders as an adjunct to other therapies. Like other forms of biofeedback, the strength of capnographic biofeedback lies in its ability to help individuals learn to regulate their own physiology, giving them power and control over their symptoms.

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