A BRIEF OVERVIEW OF THE CHEMISTRY OF RESPIRATION AND THE BREATHING HEART WAVE

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Respiration: Chemistry and Mechanics

"Respiration" is behavioral-physiologic homeostasis, a form of self-regulatory behavior, which constitutes a transport system for customized delivery of atmospheric oxygen to each and every tissue based on their specific metabolic requirements, including the transport of metabolic carbon dioxide from the cells to outside air. The "mechanics" of respiration constitute "breathing," the use of the lungs for moving oxygen, carbon dioxide, and other gases to and/or from the blood. The "chemistry" of respiration constitutes the physiology of moving oxygen from the lungs to the cells, and carbon dioxide from the cells to the lungs. Optimizing respiration means good "chemistry through good "mechanics."

In this overview, "breathing mechanics" have reference to breathing rhythmicity (holding, gasping, sighing), breathing rate, breathing depth (volume), locus of breathing (chest and diaphragm), breathing resistance (nose and mouth), and collateral muscle activity for breathing regulation (muscles other than the diaphragm). "Breathing chemistry" has reference to the ventilation of carbon dioxide through these breathing mechanics in the service of establishing adaptive respiratory chemistry. Respiratory chemistry can be monitored by measuring changes in exhaled carbon dioxide, to be discussed later, so as to ensure that the learning of breathing mechanics is truly in the service of respiration.

Good breathing "mechanics" rather than good respiratory physiology, has unfortunately become almost the exclusive focus of breathing training and learning, often along with insistence on tying it to "relaxation" training regimens in the context of specific philosophical and/or professional agenda. As a result, it is not surprising then, that at least 50 percent of therapists and trainers who teach breathing actually deregulate respiratory chemistry by inducing "overbreathing" with their instructions to trainees, not realizing that they are inducing system-wide physiological crisis through the establishment of hypocapnia, i.e., carbon dioxide deficit. Unfortunately, based on this kind of thinking, myths and misunderstandings about "good" breathing often constitute the "working knowledge" of professionals and lay audiences alike. Here are some of them:

Good breathing means relaxation.
No. Good breathing is important in all circumstances, whether relaxed or not.

Learning good breathing requires relaxation.
No. This would mean that during most life circumstances, breathing is maladaptive.

Diaphragmatic breathing is synonymous with good breathing.
No. In many instances one may begin to overbreathe as a result of switching from chest to diaphragm.

Good respiration is all about the mechanics of breathing.
No. Good breathing means ventilating in accordance with metabolic requirements.

Diaphragmatic, deep, slow breathing means better distribution of oxygen.
No. Mechanics may look letter perfect, but oxygen distribution may be poor.

Underbreathing, with the result of oxygen deficit, is common.
No. To the contrary, overbreathing is common.

Good breathing translates into optimizing respiratory physiology, and contrary to popular thinking, learning to breathe well does not simply mean deep, slow, diaphragmatic breathing in the context of learning how to relax. Adaptive breathing means regulating blood chemistry, through proper ventilation of carbon dioxide, in accordance with metabolic and other physiologic requirements associated with all life activities and circumstances: relaxation or stress, rest or challenge, fatigue or excitement, attention or open-focus, playing or working. Deregulated breathing chemistry, i.e., hypocapnia (CO_2 deficiency) as a result of overbreathing, means serious physiological crisis involving system-wide compromises that involve physical and mental consequences of all kinds, to be examined later in this overview. Evaluating, establishing, maintaining, and promoting good respiratory chemistry are fundamental to virtually any professional practice involving breathing training. Good breathing chemistry establishes a system-wide context conducive to optimizing health and maximizing performance.

Breathing training is invariably included as an important component of relaxation training, but surely does not in and of itself constitute relaxation. Breathing may be fully optimized, and hopefully is, during times of stress and challenge where relaxation is neither possible nor adaptive. Once good breathing chemistry and breathing mechanics are in place, relaxation training may then also include the establishment of stable high-amplitude breathing heart waves, i.e., parasympathetic (nervous system) tone, otherwise known as the respiratory sinus arrhythmia (RSA) and as one of the frequency ranges (HF) of what is known as heart rate variability (HRV).

Respiratory Chemistry: The Role of Carbon Dioxide in Oxygen Distribution

Blood is circulated with great precision to specific body sites based on their local and immediate metabolic requirements. Higher metabolism in more active tissues and cells generates higher levels of CO2 resulting in immediate local vasodilation (relaxation of smooth muscles with the result of increasing the diameter of the vessels), thus setting the stage for supplying the required oxygen and glucose to the associated tissues, such as to specific regions of the brain while thinking.

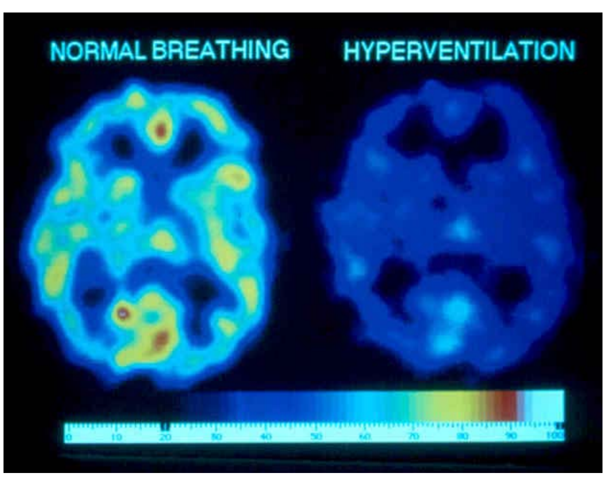
Higher levels of CO2 also lead to an immediate drop in blood and extracellular fluid pH levels through the formation of carbonic acid, thus obliging the hemoglobin to more readily distribute its oxygen to meet local metabolic requirements. Lower levels of CO2, as a result of lower metabolism, lead to blood vessel constriction (e.g., reduction in the diameter of the coronaries) and to higher levels of blood and extracellular fluid pH (less carbonic acid), thus permitting oxygen and glucose to go elsewhere where metabolic requirements are greater. In the simplest of terms, this is the biochemistry of healthy respiration.

Deregulated Respiration: Effects of Carbon Dioxide Deficit on Physiology

The most serious form of breathing deregulation is overbreathing, an all too common and serious state of behavioral-physiologic affairs. Overbreathing is undoubtedly one of the most insidious and dangerous behaviors/responses to environmental, task, emotional, cognitive, and relationship challenges in our daily lives. Overbreathing can be a dangerous behavior immediately triggering and/or exacerbating a wide variety of serious physical and mental symptoms, complaints, and deficits in health and human performance.

Overbreathing* means bringing about carbon dioxide (CO2) deficit in the blood (i.e., hypocapnia) through excessive ventilation (increased "minute volume") during rapid, deep, and dysrhythmic breathing, a condition that may result in debilitating short-term and long-term physical and psychological complaints and symptoms. The slight shifts in CO2 chemistry associated with overbreathing may cause physiological changes such as hypoxia (oxygen deficit), cerebral vasoconstriction (brain), coronary constriction (heart), blood and extracellular alkalosis (increased pH), cerebral glucose deficit, ischemia (localized anemia), buffer depletion (bicarbonates), bronchial constriction, gut constriction, calcium imbalance, magnesium deficiency, and muscle fatigue, spasm (tetany), and pain.

*Note: "Overbreathing" is a behavior leading to the physiological condition known as hypocapnia, i.e., carbon dioxide deficit. "Hyperventilation," although nomenclature synonymous with hypocapnia in physiological terms, is often used as a clinical term to describe a controversial psychophysiologic "syndrome" implicated in panic disorder and other clinical complaints.



Effects of Overbreathing on Cerebral O2:
Vasoconstrictive effects
Reduction of O2 Availability by 40 Percent
(Red = most O2, dark blue = least O2)

In this image, oxygen availability in the brain is reduced by 40% as a result of about a minute of overbreathing (hyperventilation). Not only is oxygen availability reduced, but glucose critical to brain functioning is also markedly reduced as a result of cerebral vasoconstriction.

Blood is distributed based on metabolic requirement. Overbreathing is excessive ventilation of carbon dioxide, excessive because CO_2 levels in the blood no longer accurately reflect metabolic level; the ratio of metabolic CO_2 to expired CO_2 has shifted in favor of exhaled CO_2. The consequence is a miscalculation of local metabolic requirements that leads to less than the required amount of vasodilation, or to vasoconstriction, and thus to potentially serious deficits of oxygen (hypoxia) and glucose (hypoglycemia) as well as of other required nutrients for the optimal functioning of a wide variety of tissues and physiological systems (e.g., brain, heart, and lungs). This misinformation about metabolism also triggers constriction of other smooth muscles, e.g., in the bronchioles and the gut, thus potentially exacerbating both asthma and irritable bowel syndrome.

Carbon dioxide deficit means a reduction in carbonic acid and a corresponding shift of blood and extracellular fluid pH in the alkaline direction, i.e., above the normal range of 7.38 – 7.40; alkalosis is an immediate consequence of hypocapnia. Paradoxically, this results in an *increase in oxygen saturation in the blood,* because hemoglobin does not encounter pH levels that accurately reflect current metabolic requirements and is thus less inclined than it would otherwise be to release its oxygen; the pH level does not properly reflect metabolic requirements. Thus, although oxygen saturation is maximized, oxygen distribution is withheld where in fact metabolic needs significantly exceed those reflected by the reduced CO_2 levels resulting from overbreathing.

The coupling of vasoconstriction and "disinclined" hemoglobin (because of higher pH levels) means significant compounding of oxygen distribution problems where oxygen deficits (hypoxia) are considerably greater than those brought about by vasoconstriction alone, e.g., deficits, in effect, that may exceed 50 percent in the brain. Combining these effects with glucose deficit in the brain, in the heart, and in other physiological systems can precipitate, exacerbate, and even originate serious consequences, including physiological and psychological complaints, symptoms, and syndromes of numerous kinds (see below).

Alkalosis, i.e., increased pH due to reduced levels of CO_2, leads to yet further compromises. Extracellular fluid alkalosis increases cellular excitability and contractility (e.g., neuronal excitability in the brain) and thus actually increases oxygen demand, anaerobic metabolism, and antioxidant depletion (caused by excitatory amino acids). And, in fact, yet further worsening matters, alkalosis inhibits the negative feedback normally associated with lower pH levels that limit the production of metabolic acids themselves (e.g., lactate), and hence yet further compromises performance. Blood alkalosis leads to migration of calcium ions into muscle tissue, including both smooth (e.g., coronary, vasocerebral, bronchial, gut) and skeletal tissue, resulting in increased likelihood of muscle spasm (tetany), fatigue, and pain. And, platelet aggregation is increased, thus elevating the likelihood of blood clotting.

Overbreathing is an insidious and unconscious habit, one that is not readily detectable. Overbreathing may be precipitated at stressful times of the day, during times of defensiveness and emotionality, during information overload, or upon the commencement of ordinary tasks through self-initiation or instructions from authority. Some individuals overbreathe with little provocation and may do so chronically, all day without knowing it. And, unfortunately overbreathing is even induced (often) and reinforced by professionals who teach breathing mechanics (e.g., diaphragmatic training) in the name of relaxation, improved health, and better performance. Good chemistry is fundamental to optimal behavioral-physiologic homeostasis, basic to optimizing health and performance.

Chronic Deregulation: Compensatory Behavioral-Physiologic Activity and its Price

Bicarbonates are required for controlling acidosis (when blood becomes less alkaline than normal, less than 7.38), i.e., neutralizing acids, brought about through physical activity (e.g., lactic acid) as well as through other physiologic activities (e.g., ketoacidosis as a result of diabetes). Chronic hypocapnia resulting from overbreathing ultimately leads to compensatory renal unloading of bicarbonates (inhibition of bicarbonate reabsorption in the kidneys), which lowers blood and intracellular pH toward normal levels, but in the end neither completely renormalizing nor stabilizing pH levels. Unfortunately, chronic compensatory behavior may ultimately seriously compromise buffering capabilities, resulting in reduced physical endurance and greater susceptibility to fatigue.

In addition to the loss of bicarbonates, there is also significant loss of magnesium (and phosphates) a deficiency that may ultimately lead to an imbalanced magnesium-calcium ratio critical to muscle functioning, resulting in increased likelihood of muscle fatigue, weakness, and spasm.

Although the blood pH, i.e. alkalosis, is reduced as a result of this compensatory behavior, and hemoglobin distributes its oxygen more consistently with metabolic requirements, smooth muscle constriction and its consequences remain a chronic condition (e.g., cerebral vasoconstriction, coronary constriction, bronchial constriction, and gut constriction).

Note: Individuals suffering with diabetes may overbreathe as a means to controlling ketoacidosis, i.e., reducing levels of carbonic acid. This is why biofeedback for "relaxation training," for example, was contraindicated for such individuals. Normalizing CO2 levels implicit in relaxation training, without proper attention to matter of chemistry, might well result in acidosis. The "price" for compensatory overbreathing behavior, however, is high and nevertheless needs to be seriously addressed.

Overbreathing: Effects on Health

Overbreathing, based on the chemistry of breathing described above, can trigger or exacerbate physical and psychological complaints such as: shortness of breath, breathlessness, chest tightness and pressure, chest pain, feelings of suffocation, sweaty palms, cold hands, tingling of the skin, numbness, heart palpitations, irregular heart beat, anxiety, apprehension, emotional outbursts, stress, tenseness, fatigue, weakness, exhaustion, dry mouth, nausea, lightheadedness, dizziness, fainting, black-out, blurred vision, confusion, disorientation, attention deficit, poor thinking, poor memory, poor concentration, impaired judgment, problem solving deficit, reduced pain threshold, headache, trembling, twitching, shivering, muscle tension, muscle spasms, stiffness, abdominal cramps and bloatedness. <u>It is little wonder, then, why surveys have found that up to 60 percent of all ambulance calls in major US cities are the result of overbreathing!</u>

The significance of the effects of this little known but thoroughly documented physiology can be put into perspective knowing that surveys suggest that 10 to 25 percent of the US population suffers from chronic overbreathing, and that over half of us overbreathe on frequent occasion! The following is a quotation from a book chapter written by Dr. Herbert Fensterheim (Chapter 9, *Behavioral and Psychological Approaches to Breathing Disorders*, 1994), a highly respected and internationally prominent author and psychotherapist, and it points to the fundamental importance of evaluating respiratory chemistry, i.e., overbreathing, in the mental health professions, regardless of a practitioner's school of thought or treatment paradigm:

> "Given the high frequency of incorrect breathing patterns in the adult population, attention to the symptoms of hyperventilation [overbreathing] should be a routine part of every psychological evaluation, regardless of the specific presenting complaints. Faulty breathing patterns affect patients differently. They may be the central problem, directly bringing on the pathological symptoms; they may magnify, exacerbate, or maintain symptoms brought on by other causes; or they may be involved in peripheral problems that must be ameliorated before psychotherapeutic access is gained to the core treatment targets. Their manifestations may be direct and obvious, as when overbreathing leads to a panic attack, or they may initiate or maintain subtle symptoms that perpetuate an entire personality disorder. Diagnosis of hyperventilatory [overbreathing] conditions is crucial."

Chronic vasoconstriction, magnesium-calcium imbalance, buffer depletion, and alkalosis (higher levels of blood and extracellular pH levels) as a result of overbreathing may in predisposed individuals trigger or exacerbate: phobias, migraine phenomena, hypertension, attention disorder, asthma attacks, angina attacks, heart attacks, cardiac arrhythmias, thrombosis (blood clotting) panic attacks, hypoglycemia, epileptic seizures, altitude sickness, muscle weakness and spasm, sexual dysfunction, sleep disturbances (apnea), allergy, irritable bowel syndrome (IBS), repetitive strain injury (RSI), and chronic fatigue.

In an important recent review article on the subject of hypocapnia (CO2 deficit) in the *New England Journal of Medicine* (J. Laffey and B. Kavanagh, 4 July 2002), the authors say:

> "…extensive data from a spectrum of physiological systems indicate that hypocapnia has the potential to propagate or initiate pathological processes. As a common aspect of many acute disorders, hypocapnia may have a pathogenic role in the development of systemic diseases" (pages 44 and 46). And, they go on to say, "Increasing evidence suggests that hypocapnia appears to induce substantial adverse physiological and medical effects" (page 51).

Long-term vasoconstriction may also lead to ischemia in the brain and the heart (anemia in cells not adequately supplied with oxygen), result in reduced neurotransmitter synthesis that contributes to the onset of depression and other psychological syndromes, and chronically lower the threshold for most of the complaints listed above, e.g., chronic vasoconstriction and increased systemic vascular resistance may reduce the threshold for elevated blood pressure or precipitate angina attack in predisposed individuals.

It is estimated that the primary complaint of one third of all patients in general medical practice is fatigue, a condition that may actually be brought on and/or exacerbated by buffer depletion resulting from overbreathing, and a condition (fatigue) in and of itself that can be assessed through CO2 measurement (capnometry) to be described later in this overview. On this basis alone, some prominent physicians in both Europe and America assert that capnometers, like blood pressure devices, should be on the desktop of every general and family practitioner.

It is estimated that more than a third of all those who suffer with asthma overbreathe, a condition potentially leading to immediate bronchial constriction and asthma attack. The "struggle" to breathe and fear of "not getting enough air" can easily lead to "panicky" breathing where vicious circle overbreathing may result in a progressive worsening of hypocapnia-induced bronchial constriction and increased airway resistance. Teaching good breathing mechanics to people with asthma through diaphragmatic breathing can very significantly improve breathing efficiency by increasing volume, reducing rate, establishing rhythmicity, and eliminating collateral muscle movement not required for good breathing. In effect, it reduces the "struggle" to breathe by introducing an effortlessness form of breathing that also provides for a sense of mastery over the debilitating effects of the condition. This training, however, can itself easily result in overbreathing through a combination of the "success" of the method itself (increased efficiency, volume) and the continued motivation "to get enough air," and where neither the therapist nor the patient are familiar with overbreathing and its effects.

Documented medical savings of 45 percent over a five year period in heart attack patients following only six breathing training sessions, led to legislation in Holland that all cardiac rehabilitation centers offer breathing training to patients. Unfortunately, this little known research and its highly practical implications remain relatively unknown to most professionals working in American cardiac rehabilitation centers, where the importance of behavioral respiratory physiology has simply not been introduced. The importance of breathing training in cardiovascular health is yet further supported by the article in the *New England Journal of Medicine* (page 50), where the authors point out that "*hypocapnia has been clearly linked to the development of arrhythmias, both in critically ill patients and in patients with panic disorder."*

How can "simple" breathing training significantly influence the outcome of cardiovascular rehabilitation in patients who overbreathe? Consider the following: A survey of studies on overbreathing and coronary constriction show a reduction of blood volume by about 50 percent (a 23 percent reduction in coronary diameter), a significant reduction in compromised individuals; and, extreme coronary constriction as a result of overbreathing has also been identified in a subpopulation of patients. Increased platelet aggregation brought about by hypocapnia may precipitate blood clotting, i.e., thrombosis. Buffer depletion resulting from long-term overbreathing, as described earlier, may also significantly contribute to the onset of arrhythmias and other cardiovascular abnormalities. Increased vascular resistance as a result of vasoconstriction and alkalosis brought about through chronic overbreathing may trigger hypertension in predisposed individuals. Hypocapnia leads to cellular excitability and to increased contractility of the heart, increasing oxygen demand while oxygen availability is sharply decreased. And, the upward pH shift brings on calcium migration into muscle tissue, increasing the likelihood of arterial (coronary) spasm. Normalizing breathing chemistry reverses these effects.

The *New England Journal of Medicine* article goes on to point out that clinically significant overbreathing in pregnant women is commonplace, and that during childbirth, *"...further lowering of the partial pressure of arterial CO2 - even for a short duration - such as during anesthesia for cesarean section - may have serious adverse effects on the fetus."* The implications of this statement are staggering when considering that some child-birthing techniques used by many thousands of women (western) worldwide actually engaged women in the practice of extreme forms of overbreathing during childbirth.

Overbreathing during wakefulness is seriously implicated as an important variable in the origin and in the onset of sleep apnea. "*Hypocapnia is a common finding in patients with sleep apnea and may be pathogenic*," according to the same article in *New England Journal of Medicine*.

The seriousness of the effects of hypocapnia are made absolutely clear in the *New England Journal of Medicine* review article, written for the express purpose of warning physicians about their use of hypocapnia as a means to controlling symptoms and conditions resulting from injury and disease, as well as its widespread use in general anesthesia. In fact, the impact of hypocapnia on cerebral blood flow and blood volume is so dramatic, according the article, that almost 50 percent of emergency physicians and 36 percent of neurosurgeons actually induce hypocapnia to control of life-threatening intracranial swelling resulting from head trauma or brain injury.

Overbreathing: Effects on Cognition

Cognitive and perceptual deficits are perhaps most clearly understood by newcomers to this physiology by examining the effects of hypoxia on the behavior of pilots. Every pilot knows about the cognitive and perceptual deficits resulting from the effects of hypoxia in high altitude chambers, including impaired decision-making, perceptual motor skills, information processing, problem solving, task completion, memory, thinking, and communication effectiveness. Serious cerebral hypoxia means that even the easiest of tasks become significant mental challenges, e.g., simple navigational calculations during an engine-out procedure. In fact, overbreathing is routinely monitored in fighter pilots while in flight. Particularly noteworthy, as is often emphasized by on-looking observers, is the fact that these performance decrements go completely undetected by those actually suffering from the hypoxia. Overbreathing at sea level and the resulting hypoxia produce precisely these same effects!

The potent impact of overbreathing on cerebral functioning is made clear in the recent article in the *New England Journal of Medicine* in the description of the use of hypocapnia for controlling intracranial swelling in otherwise life-threatening brain trauma circumstances: "*Hypocapnic alkalosis decreases cerebral blood flow by means of potent cerebral vasoconstriction, thereby lowering intracranial pressure*." The dramatic impact of overbreathing on cognitive function is put into further perspective, when the authors describe the widespread and deliberate induction of hypocapnia during general anesthesia (e.g., for reducing the need for sedatives), as follows:

"The causative role of hypocapnia in postoperative cognitive dysfunction is underscored by the finding that exposure to an elevated partial pressure of arterial carbon dioxide [i.e., normalizing CO2 levels] during anesthesia appears to enhance postoperative neuropsychologic performance."

Cognitive, perceptual, and motor skill deficits, brought about by hypoxia (oxygen deficit) are yet further exacerbated by cerebral hypoglycemia (glucose deficit, as a result of vasoconstriction) that may compromise brain functioning to a yet greater degree. The potentially debilitating combination of cerebral oxygen and glucose deficits resulting directly from overbreathing may seriously compromise and/or disrupt ability to attend, focus, concentrate, imagine, rehearse the details of an action (e.g., golf swing), initiate performance, play a musical instrument, sing, engage in public speaking, and perform all kinds of other complex tasks.

There is a fine line between vigilance and stress. In the transition from vigilance to stress, i.e., from positive attentiveness to guarded defensiveness (fight-flight behavioral patterns), overbreathing may be immediately instated with its debilitating effects occurring within less than a minute. This same kind of transition may occur when task-demand exceeds a certain level of complexity or when relationship challenge exceeds a certain level of emotionality: overbreathing as a component of defensive posturing takes over. *Task-induced overbreathing for example* can insidiously and unsuspectingly contribute to the degradation of human performance, insidious because the performer is neither likely to be aware that overbreathing is taking place, nor have any idea whatsoever as to its effects. Performers who are task-induced "overbreathers" are good candidates for breathing chemistry training.

The implications of overbreathing and its regulation for working with children and adults suffering with attention deficits are significant. Low cerebral CO2 as a result of overbreathing shifts the EEG power spectrum downwards and elevates the presence of theta EEG activity, the frequency domain of principal interest to neurofeedback practitioners who seek to reduce theta activity in clients who suffer attention deficit disorder. Before beginning such work it truly behooves practitioners to normalize the chemistry of breathing, a fundamental system-wide physiological consideration, before beginning neurofeedback or other forms of behavioral-physiologic training.

Overbreathing: its Effects on Emotion

Cerebral hypoxia and cerebral hypoglycemia not only have profound effects on cognition and perception but also on emotionality: apprehension, anxiety, anger, frustration, fear, panic, stress, vulnerability, and feelings of low self-esteem. Cerebral (brain) oxygen and glucose deficits may trigger "disinhibition" of emotional states, i.e., release of emotions otherwise held "in check." Loss of emotional control, intensification of emotional states, and exacerbation of debilitating stressful states of consciousness may result from overbreathing in challenging and adverse circumstances, e.g., flying phobias and debilitating public speaking anxiety. Emotional discharge in challenging environments itself may, of course, further exacerbate cognitive and other performance deficits.

Failure to understand the source of physical sensations resulting from overbreathing, e.g., light-headedness, tingling of the skin, tightness of the chest, sweaty hands, and breathlessness, typically leads to a false interpretation of their meaning. The incorrect, and usually negative, self assessment that may result, e.g., "I am losing control," is likely to elicit secondary emotional responses (e.g., fear) and further exacerbate the ones directly resulting from cerebral oxygen and glucose deficits. And indeed, practitioners and trainers themselves, not familiar with the effects of overbreathing, may unfortunately also misinterpret these secondary effects, taking them as evidence supporting their own biases about the significance of the kinds of complaints reported by the client, e.g., "relaxation moves you closer to yourself, and this makes you uncomfortable. Overworking is your way of protecting yourself."

Sometimes overbreathing is deliberately induced for the very reason that it can trigger emotional memories and states, e.g., rebirthing. Stanislav Grof's Holotropic Breathwork, widely known for its use in triggering emotional and memory release, is an excellent example of how overbreathing lowers the threshold for emotional expression. Some breathing inductions used in natural child birth, for example, involve extreme forms of overbreathing, based on the premise that disorientation reduces capacity to focus on pain; from a respiratory chemistry perspective, however, this amounts to induction of system-wide crisis with potentially adverse effects on the infant.

Overbreathing: Effects on Performance

Compromising the blood buffering system (i.e., reduced capacity to regulate acidosis) means reduced physical capacity and endurance, ranging from limiting athletes in their pursuit of achieving peak levels of physical performance, to contributing to the incapacitation of individuals with fatigue and unable to perform the simplest of tasks without exhausting their supply of buffers.

Incrementally increasing the workload on an exercise bike or treadmill increases metabolism, and hence the output of carbon dioxide. Normal ventilation means that the CO2 exhaled is consistent with level of metabolism; there is no overbreathing. Eventually, however, when buffers become depleted and can no longer neutralize lactic and other acid byproducts, overbreathing becomes a short-term solution to the resulting acidosis, i.e., carbonic acid is reduced, thus offsetting the build up of other acids. Monitoring CO2 levels during exercise on an exercise bike or treadmill permits an observer to take note of this critical point, the point at which overbreathing is itself a compensatory response to buffer depletion, the point at which physical exhaustion can be identified. And, as described previously, chronic overbreathing itself may lead to buffer depletion, thus ultimately reducing physical capacity and endurance to a point where simple exercise becomes equivalent to the maximum endurance effort of an athlete.

Buffer depletion physiology has very significant implications for performance and health. Running out of buffers with exercise equivalent to walking to work, crossing a few streets to lunch, or preparing dinner for the family means "physical" exhaustion doing the simple physical chores that define the daily routine of life. Overbreathing may not only lead to buffer depletion but may then also become its own short-term solution to the resulting acidosis, i.e., a vicious circle syndrome. This state of affairs can be observed by exercising on an exercise bike or treadmill and noting the point at which there is a drop in carbon dioxide level, the point at which overbreathing is engaged.

Professional and lay audiences both ponder the ways in which "stress" ultimately has its effects on health and performance. What are the mediating variables that lead to behavior-physiologic deregulation? One important contributing factor may be the way in which one encounters challenge: bracing or embracing, defensive-posturing or life-engaging? The defensive or bracing mode often includes overbreathing (part of the "fight-flight" behavioral configuration) that may lead to the fatigue symptoms and complaints associated with the effects of buffer depletion and magnesium deficiency, along with the wide range of physical and psychological effects previously described.

The "fatigue" associated with overbreathing may be misidentified as "depression." Exercise may be "prescribed" when rest is in order, where exercise will actually exacerbate the problem and is contraindicated. Buffer depletion, resulting from exercise and associated compensatory overbreathing, may in fact precipitate cardiac arrhythmias even in otherwise healthy individuals. Rest will permit build-up of the buffers, but upon returning to a challenging environment without breathing and other forms of self-management training, overbreathing is likely to be reinstated, once again resulting in buffer depletion and a relapse of fatigue and associated effects of "stress." Deregulated respiratory chemistry constitutes a behavioral-physiologic mechanism that may directly account for some of the effects of "stress" on homeostasis and self-regulation.

Respiratory Training: General Considerations

Fritjof Capra, famed physicist and systems theorist, states his position on the mindbody dichotomy so well when he says, "the organizing activity of living systems, at all levels of life, is mental activity" (*The Web of Life,* 1996). In other words, there simply is no dichotomy, that all of life is itself inherently "mindful." Thus, in this thesis there is no distinction between physiological or psychological crisis; defensive posturing or bracing and life-engaging or embracing are "mindful" frames of physiological reference, comprising what might be described as "life" postures.

These "life" postures are fundamental operating-definition culture-based concepts as can be seen in Western psychology where there is emphasis on defensiveness, and in Eastern philosophy and practice (e.g., meditation), where there is emphasis on embracement of chi, i.e., life or breath. Both of these postures are profoundly reflected in the chemistry and in the mechanics of respiration.

Breathing evaluation and training bring together differing western schools of thought and tradition, including physiology, psychology, healthcare, and human performance with the promise of weaving them together with Eastern thinking, traditions, and practice into an active, personal, and mindful participation in behavioral-physiologic self-regulation for health and performance.

Seeing "physiology as mindful" carries with it an important implication: it is the "ego" part of the mind that identifies itself as "separate" from the "body," giving rise to the mind-body dichotomy through its indignant claim on ownership of all of the mind, wherein the mind necessarily came to be viewed as "our" unconscious, rather than as a property of the fundamental essence of life itself and in all of its forms. Accessing the body, then, for the "mindful physiology" oriented practitioner, means accessing the mind: intuitions, images, feelings, archetypes, and meaning itself. Accessing the mind through body sensitivity training is fundamental to what has come to be known as biofeedback and is the basis for breathing evaluation and training. It is little wonder that breathing is a point of physio-spiritual connection in Eastern philosophical thinking.

As Capra points out in his book, *The Web of Life*, the whole is not simply greater than its parts but actually provides for the definition, the very identity, of the parts themselves. Overbreathing sets the stage for crisis, even for trauma, and for a consciousness of defensive posturing and bracing. It engages state-dependent behaviors, even state-dependent personalities, which are protective in nature offering the prospect of safety in a threatening world; overbreathing becomes a doorway into a different consciousness where one may disconnect, isolate, or flee, but pay the price of behavioral physiologic deregulation. Changing consciousness, means changing the definition of constituent physiological dynamics: rapid heart rate is a sign of stress in the context of defensiveness, whereas it is a sign of joy in the context of embracement. Good respiratory chemistry and mechanics set the stage for "embracement," rather than defensiveness, as a "life" posture. Wellness is ultimately about embracing, about the heart, about bringing together the mindfulness of physiology with the personal consciousness. Health is about seeking, presence, and availability, not about ego and defensiveness. When naked, don't overbreathe, be there.

Learning about the behavioral physiology of respiration offers the prospect of bringing easy to understand, highly practical, and easy to implement educational applications of "mindful-physiology" to healthcare and human performance practitioners everywhere. Everyone acknowledges some measure or responsibility for breathing, as is evidenced by everyone's use of the pronoun "I." Breathing training is an ideal context in which to teach people about the mindful nature of physiology, where self-regulation training for health and performance can make a powerful impact on the practical thinking of large audiences within a short time. The theme is: "The whole body is the organ of the mind, not just the brain. Our minds are the music that our bodies play to the universe."

Respiratory Training: Specific Considerations

Breathing chemistry training does NOT replace breathing mechanics training; the two together comprise true respiratory training (i.e., getting O2 to the cells and CO2 back to the lungs). There is NO specific breathing protocol, technique, or program that constitutes the "right one," however, keeping respiratory chemistry in the adaptive window is a critical consideration in most any kind of breathing training. There are numerous approaches to teaching the mechanics of adaptive breathing that permit practitioners to integrate breathing evaluation and training into their work based on professional background, expertise, experience. Unfortunately, however, in very few cases is the chemistry of breathing included as a component of the training.

Breathing is a complex behavior. It is voluntary and involuntary. It is greatly influenced by emotion. It is synchronized with complex speech behavior. Basic neurophysiological control of breathing originates in the respiratory centers located in the brain stem, the pons and medulla, where breathing rate and volume are regulated based on CO2 levels. While in a coma, breathing mechanics (rate and volume) track CO2 levels precisely. There are other breathing centers throughout the brain including the limbic system (emotion), the speech areas of the brain, and the frontal cortex (voluntary control). These other regulatory centers may interfere with adaptive breathing, resulting in deregulated breathing, overbreathing that is often associated with breath holding, gasping, sighing, chest breathing, rapid breathing, reverse breathing (contracting the diaphragm while breathing out), and so on. *Training for adaptive breathing chemistry, in most instances, means restoring regulated breathing through reinstatement of the basic brain stem breathing reflex.*

How is overbreathing identified? Without monitoring CO2 levels, there is simply no way of knowing. Use of the *capnometer* is the only practical and technically reliable method for detecting it with certainty. Arterial carbon dioxide (PaCO2) can be measured directly through invasive monitoring, or indirectly by means of measurement of CO2 content in exhaled air. Measurement of CO2 at the end of exhalation, or at the "end" of the "tide" of the air breathed out, is known as "end-tidal carbon dioxide," or ETCO2, and is under normal circumstances highly correlated with invasive arterial measurement. Capnometry is used in virtually every surgery room and critical care unit in America, and is based on textbook physiology and highly reliable technology.*

The objective of breathing training while "at rest" is to restore proper breathing chemistry (CO2 levels), establish breathing rhythmicity (reduction of holding, gasping, sighing), lower breathing rate, increase breathing depth, shift the locus of breathing from chest to diaphragm, encourage nasal breathing, relax musculature during exhalation, reduce collateral muscle activity, and establish a stable presence of high amplitude breathing heart wave activity (parasympathetic tone, RSA). Training for good breathing chemistry involves learning how to:

(1) evaluate breathing both at rest and in the context of multiple kinds of challenge;
(2) teach the physiology and psychology of respiration;
(3) identify the sensations of overbreathing, and reinstate the basic brain stem breathing reflex;
(4) interpret physiological experience, e.g., deregulated vs. regulated breathing;
(5) train breathing mechanics: rhythmicity, volume, rate, resistance, and locus of control;
(6) instate prophylactic (deliberate) techniques for consciously disengaging or preventing overbreathing;
(7) configure new patterns of behavioral-physiologic defensive posturing, without overbreathing;
(8) establish "embracement physiology" where overbreathing is not a "mindful" component; and
(9) generalize new patterns of breathing that normalize chemistry in diverse life circumstances.

In summary, training involves: (1) education, (2) learning prophylactic techniques, (3) reinstating the basic respiratory reflex mechanism, (4) learning new patterns of defensive posturing, and (5) learning to engage "embracement" physiology by establishing new chemistry and its associated "physiologic mindfulness."

Breathing evaluation and training may be useful for behavioral physiologic applications by healthcare providers and patients, performance trainers and athletes/artists, corporate trainers and trainees, behavioral health professionals and clients, human service providers and clients, consultants and self-improvement trainees, educators and students, and academicians and researchers. Examples of performance training applications include: improving memory, enhancing thinking and problem solving skills, improving concentration (playing an instrument), attention training (e.g., attention deficit), reducing anxiety (e.g., public speaking, test taking), managing stress, managing anger, decreasing fatigue, increasing alertness and readiness, reducing muscle tension, diminishing physical pain, facilitating relaxation, facilitating disciplines of inner directedness (e.g., meditation), maximizing performance training (e.g., flight training), natural child birth preparation, peak performance training (e.g., athletes and coaches), and evaluating and improving physical condition.

***Measurement of End-Tidal CO2:**

The presence of a "gas" is measured in terms of its pressure, and more specifically in terms of its relative pressure contribution to total atmospheric pressure, i.e., its partial pressure. Total atmospheric pressure on a standard day at sea level is 760 millimeters of mercury (mmHg), and is comprised of the partial pressures of all of the gases present in the air, e.g., partial pressure oxygen is 19 percent of the total pressure, or 144 mmHg. Carbon dioxide in atmospheric air is so low that capnometer readings during inhalation are nil. At rest, exhaled ETCO2 should be approximately 5 percent of the total pressure, or 38 mmHg (also known as units of "torr"). Individual metabolism varies; normal range is 35 to 45 mmHg, increasing with exercise.

Heart Rate Variability: the Breathing Heart Wave

"Wellness is ultimately about embracing, about the heart, about bringing together the mindfulness of physiology with the personal consciousness. Health is about seeking, presence, and availability, not about ego and defensiveness." The breathing heart wave speaks to the physiology of this thinking.

Heart rate changes in cycles. These cycles comprise what is known as "heart rate variability," or "HRV" as it is known in the literature. One of these cycles tracks the breathing pattern: "breathing in" increases heart rate, and "breathing out" decreases heart rate (also known as the respiratory sinus arrhythmia, or RSA). This pattern of heart rate change (variability) increases in amplitude as one relaxes, decreases in amplitude as one becomes tense, and disappears altogether when one becomes highly anxious, stressed, or fearful.* Monitoring this heart rate cycle, the breathing heart wave, provides for direct observation of *parasympathetic* nervous system activity, and is hence known as the parasympathetic HRV frequency.

***Important note:** Greater breath size resulting from the slowing of breathing and/or diaphragmatic breathing may have a significant impact on the amplitude of the breathing heart wave (RSA), and should not be confused with an increase in parasympathetic activity.

Heart rate VARIABILITY, where rate tracks breathing as described above, is a significant physiological marker to good relaxation training, and should not to be confused with heart RATE itself. Variability is measured by looking at heart rate changes from beat to beat. That is to say, heart rate is recalculated with every beat, and is not averaged with preceding beats as is usually done in monitoring heart rate by healthcare professionals and performance trainers. Monitoring relaxation based on average heart rate, rather than variability, is an insensitive and unreliable measurement tool. In fact, relaxation often does not result in reduced heart rate (averaged value), nor does anxiety necessarily result in elevated heart rate.

Breathing training for relaxation includes good breathing mechanics (e.g., diaphragmatic), good breathing chemistry, and the establishment of a reliable high amplitude breathing heart wave.

Heart Rate Variability: Other Frequencies

When changes in heart rate are analyzed formally, as in a Differential Fourier Transform (DFT) by frequency, the predominant frequency ranges of heart rate variability can identified by their higher amplitudes. Three such relatively high amplitude frequency ranges have been proven to be sensitive indicators of autonomic nervous system regulation and associated changes in emotion, alertness, attention, and stress. These are the Very Low Frequency (VLF, 0.0033 to 0.04 Hz), Low Frequency (LF, 0.04 to 0.15 Hz), and High frequency (HF, 0.15 to 0.4 Hz, RSA, or breathing heart wave) ranges. Monitoring and recording HRV in these frequency bands has proven useful in tracking and evaluating autonomic nervous system function.

The HF frequency band is widely known as the "parasympathetic" HRV frequency band whereas the LF frequency band is sometimes referred to as the sympathetic HRV frequency band. The parasympathetic (HF) and sympathetic (LF) ranges of heart rate variability are only two regions of the HRV spectrum that are of interest to practitioners reviewing the practical implications of an extensive HRV research literature. A third frequency band is VLF, which has recently been associated with ruminative thinking and is now of serious interest as well. These three frequency domains along with the ultra low frequency domain (ULF) are also of interest to researchers who study HRV behavior and its relationship to the presence of cardiovascular disease.

A note of caution: Conventionally, the range of HRV frequencies associated with parasympathetic tone (the RSA) is often restricted to the High Frequency (HF) band of 9 to 24 cycles per minute. Although this assumption may be misleading, the HF band is nevertheless often taken to be a realistic frequency range for breathing rate and therefore for parasympathetic tone (the RSA).

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