

# BREATHING

## Aligning Mechanics with Chemistry

Professional School of Behavioral Health Sciences  
Behavioral Breathing Sciences, a Division of the Professional School

Peter M. Litchfield, Ph.D.

Breathing and its potential effects on our lives, positive and negative, are enormous. Appreciating this enormity is significantly enhanced by learning about the amazing physiology of breathing, which together with understanding breathing as motivated behavior, can account for the profound and far-reaching effects of breathing on health and performance.

Millions of people from around the world include breathing learning interventions in one way or another in their professional and/or personal lives for a multitude of reasons. Most of them, however, focus on the mechanics of breathing without even so much as a thought about its chemistry, that is, the role of mechanics in optimizing internal respiration and its associated chemistry, e.g., pH regulation of blood plasma. Learning about alignment of breathing mechanics with respiratory chemistry helps to (1) avoid misguided self-interventions that can have adverse effects, (2) avoid misinterpretations of the outcomes of breathing self-interventions, (3) prevent missed learning opportunities at the expense of ourselves and/or clients, and (4) significantly expand the scope and effectiveness of breathwork.

The effects of compromised respiratory chemistry, because of learned dysfunctional mechanics (habits), can be immediate and disturbing. Statistics suggest that tens of millions of people worldwide suffer with the profound and misunderstood symptoms and deficits of learned dysfunctional breathing habits that compromise respiratory chemistry. Surveys suggest that perhaps 60% of ambulance runs in the major USA cities are a result of acute symptoms brought on by dysfunctional habits, often learned early in life. Unfortunately, these habits are rarely identified by healthcare practitioners, their effects mistakenly attributed to other causes, and their resolutions prescriptive in nature where focus is on symptoms rather than on causes, e.g., drug prescriptions.

Breathwork can help provide a solution to this challenge. Precisely the same principles by which people learn dysfunctional breathing habits can also be implemented for overcoming these same habits and/or learning new breathing habits that enhance health, learning, performance, awareness, creativity, and communication. Learning about how mechanics and chemistry work together is fundamental to understanding the potential effects of making conscious changes in breathing mechanics on respiratory chemistry, e.g., improving attention by enhancing blood flow to the brain. This article provides a brief overview of these considerations, while introducing some basic respiratory physiology relevant to improving the effectiveness of breathwork.

## RESPIRATION

Respiration can be subdivided into three phases: external, internal, and cellular. *External respiration* is about breathing mechanics, moving air in and out of the lungs, e.g., slow/fast, deep/shallow, mouth/nose, diaphragmatic/chest, rhythmic/dysrhythmic, exhale completed/not completed, and so on. *Internal respiration* is about oxygen distribution to tissues, carbon dioxide management, and acid-base regulation (pH and electrolyte balance) of extracellular body fluids (e.g., blood plasma). *Cellular respiration* is about creating ATP molecules (adenosine triphosphate) in the mitochondria of cells, which are then broken down by cells for energy. Carbon dioxide generated during cellular respiration is a precious gas that ultimately makes possible moment to moment acid-base regulation (as will be seen).

## BREATHING MECHANICS (external respiration)

Breathing and respiration are not the same phenomenon. Respiration is a subset of breathing. Besides providing for respiration, breathing serves us in many and diverse ways.

**Breathing is behavioral.** It serves us in powerful and unsuspecting ways. Breathing habits, good and bad, are learned unconsciously, and sometimes consciously, for self-regulating emotions, cognitions, personality, coping styles, physiology, health, performance, and consciousness. This is to say that breathing is psychological in the sense that experience sets the stage for its reconfiguration. Embedded in this reconfiguration is a personal history that regulates breathing based on the principles of learning, perception, motivation, reinforcement (benefits), attention, and memory. The richness of the psychology of breathing provides for both its far-reaching benefits and for its, all too frequent, profoundly debilitating effects (e.g., 60% of USA ambulance runs).

**Respiration is reflexive.** External respiration is about the regulation of breathing mechanics by brainstem reflex mechanisms governed by moment to moment changes in respiratory chemistry, that is, changes in extracellular pH, oxygen concentration ( $PO_2$ ), and carbon dioxide concentration ( $PCO_2$ ). Although breathing mechanics continuously shift as a function of being bored or excited, stressed or relaxed, upset or pleased, meditative or physically challenged, respiration generally remains within an optimal respiratory envelope. Unless an unconscious habit or intentional manipulation gets in the way, respiratory requirements will dictate the coordination of breathing mechanics in the context of other interacting behaviors, e.g., eating and breathing. It would, of course, make little sense that breathing could serve respiration only when one is relaxed or in a positive space; if so, given what daily life is usually about, respiration would be compromised most of the time.

Practitioners from diverse disciplines and perspectives focus on manipulation of breathing for achieving beneficial outcomes, that is, **self-interventions** that involve “doing the breathing” in prescribed ways. Unfortunately, however, one of the outcomes of prescriptive breathing is not infrequently deregulated respiration, and unfortunately even the acquisition of dysfunctional habits where both practitioners and clients misunderstand and misinterpret the associated physical and mental changes.

Healthy breathing provides for **self-regulation** of mechanics in the service of chemistry, except where respiratory chemistry is intentionally manipulated for reasons such as identifying dysfunctional habits and exploring their effects, or for personal and therapeutic consciousness explorations (e.g., Holotropic breathing). Self-regulatory breathing means “allowing the breathing” while simultaneously breathing for meeting other objectives, e.g., talking, meditating, relaxing, exploring.

Optimal respiratory health means maintaining a stable “chemical axis of breathing” wherein internal respiratory requirements are immediately and expeditiously addressed, despite the highly variable acrobatics of breathing mechanics during daily life that may be serving us in so many other important ways, e.g., talking. Understanding this connection of breathing mechanics with breathing chemistry points to the most fundamental, practical, and profound factors that account for:

(1) the far-reaching effects of dysfunctional breathing habits, such as disturbed extracellular pH (e.g., blood plasma), deregulated electrolyte balance (e.g., bicarbonate), compromised blood flow (e.g., brain and heart), unfriendly hemoglobin (compromised delivery of  $O_2$ ), compromised muscle function (e.g., jaw tension and pain), fatigue, mood changes, and performance deficits;

(2) the surprising benefits of good breathing habits and breathing self-interventions, such as improved physical performance (e.g., sports), symptom abatement (e.g., panic), improved cognition (learning, memory, and attention), enhanced task performance (e.g., test taking), successful management of emotions and stress (e.g., anxiety, anger), expanded consciousness (e.g., being present), improved self-awareness (e.g., sense of self), and better overall health (balanced chemistry).

## BREATHING CHEMISTRY (internal respiration)

Many people believe that good breathing is about moving as much oxygen (O<sub>2</sub>) as possible *into the blood*, while simultaneously eliminating (excreting) as much carbon dioxide (CO<sub>2</sub>) as possible *from the blood*, through “the right” breathing mechanics. This view is both uninformed and simplistic. Yes, O<sub>2</sub> delivery to body cells is essential, of course, but the best way to accomplish this is not so obvious. And yes, excretion of *excessive* CO<sub>2</sub> is critical, but not all of it, only some of it. Contrary to the belief of many, CO<sub>2</sub> is a precious body substance and its ever presence is required not only for health but for life itself.

External respiration (breathing mechanics) is regulated from breath to breath by chemo-regulatory reflexes located in the brainstem. These reflexes are regulated based on pH of arterial blood plasma (pHa) and cerebrospinal fluid, CO<sub>2</sub> concentration in blood plasma (PaCO<sub>2</sub>) and cerebrospinal fluid, and by O<sub>2</sub> concentration in arterial blood plasma (PaO<sub>2</sub>). These reflexes operate breathing through the diaphragm and the internal intercostal muscles while at rest. This is one reason why if chest breathing predominates, based on an unconsciously learned breathing habit (where “feeling in control” may take precedence over allowing for the reflexes), that diaphragmatic training can be so fundamentally important, i.e., clients may learn to prefer mechanics that are consistent with good chemistry.

Acid-base balance is about *pH regulation*, i.e., hydrogen ion concentration (pH = power of hydrogen). An *aqueous* (water) solution is neutral when the pH is 7.0. Solutions with a pH of less than 7.0 are acidic and solutions with a pH of higher than 7.0 are alkaline. The body keeps blood plasma within very tight limits of pH, optimally 7.38-7.40, but generally within a range of 7.35-7.45. Hence, as pH drops blood plasma becomes less alkaline (not acidic) and when it rises it becomes more alkaline. Values of less than 7.35 mean *acidemia* and values above 7.45 mean *alkalemia*.

*Overbreathing*, which is the most common form of learned dysfunctional breathing, leads to a CO<sub>2</sub> deficit (*hypocapnia*) resulting in *respiratory alkalosis* (pH higher than 7.45). *Underbreathing*, which is unusual, leads to excessive accumulation of CO<sub>2</sub> (*hypercapnia*) resulting in *respiratory acidosis* (pH lower than 7.35). Both conditions can result in profound physiological changes responsible for a wide range of symptoms and deficits, short term and long term. Low arterial CO<sub>2</sub> concentrations, however, may not necessarily be the result of a dysfunctional habit, but rather a compensatory response to some other physiological compromise, e.g., metabolic acidosis such as lactic acid build up (lactic acidosis) during anaerobic exercise, or cardiac insufficiency in patients with heart conditions.

The Henderson-Hasselbalch (H-H) equation describes pH regulation of blood plasma and other extracellular fluids, as follows (simplified format):

$$pH = [HCO_3^-] \div PaCO_2, \text{ OR } [H^+] = PaCO_2 \div [HCO_3^-]$$

where, [HCO<sub>3</sub><sup>-</sup>] = bicarbonate ion concentration

where, [H<sup>+</sup>] = hydrogen ion concentration

where, PaCO<sub>2</sub> = arterial CO<sub>2</sub> concentration (partial pressure arterial CO<sub>2</sub>)

where pH is the reciprocal of hydrogen ion concentration

Bicarbonates are regulated by the kidneys and the PCO<sub>2</sub> concentration by breathing. The kidneys are very slow to act, and don't even begin to compensate for changes in pH for at least eight hours and may take up to five days to make its full contribution toward normalizing pH. Breathing on the other hand can immediately effect pH level, within seconds, positively by the action of reflex mechanisms and positively OR negatively by learned breathing habits. It is here where the psychology of breathing can make its grand entry into physiology through its role in the regulation of the H-H equation. Consider the following rewrite of the equation: ***Acid-base physiology = kidney function ÷ breathing behavior.***

Breathing mechanics, controlled by brainstem reflexes (external respiration), normally regulate the pH of extracellular body fluids, including blood plasma, cerebrospinal fluid, interstitial fluid (that surround all cells in the body), and lymph. But, learned breathing habits can get in the way of these reflexes leading to insidious and generally unidentified outcomes by both practitioners and their clients.

About 98.5% of oxygen diffused into the blood of the pulmonary capillaries surrounding the alveoli of the lungs, is carried in the blood by hemoglobin in red blood cells. Hemoglobin delivers its oxygen based on blood plasma O<sub>2</sub> concentration (PaO<sub>2</sub>) as per the oxyhemoglobin dissociation curve. As PaO<sub>2</sub> drops in busy tissues hemoglobin begins to deliver its oxygen. The CO<sub>2</sub> concentration and the pH of cytosol in red blood cells significantly affect when and where hemoglobin will deliver its oxygen (Bohr Effect). If a tissue is busy at work it will generate more CO<sub>2</sub> which diffuses into the red blood cell. The presence of more CO<sub>2</sub> and the reduced pH of the cytosol (CO<sub>2</sub> forms H<sub>2</sub>CO<sub>3</sub>, carbonic acid) reduces hemoglobin's affinity for oxygen (changes its conformation), leading to an earlier distribution of its oxygen as per the Bohr effect (that is, releasing oxygen at higher levels of PaO<sub>2</sub>). Very importantly, also resulting from increased CO<sub>2</sub> concentration and pH of cytosol in red blood cells, hemoglobin will release nitric oxide (NO), a powerful vasodilator, providing for increased blood flow and volume in busy tissues that require more oxygen and glucose.

Brainstem reflex mechanisms regulate breathing mechanics (external respiration) such that the correct CO<sub>2</sub> concentration is maintained in the alveoli of the lungs (where gas exchange takes place). This ensures that blood moving through the pulmonary capillary network returns to systemic circulation with a CO<sub>2</sub> concentration that balances the H-H equation, thus keeping pH within normal limits. Thus, when one intentionally ventilates by taking large breaths, slow or fast, diaphragmatically or in the chest, PaCO<sub>2</sub> concentration can drop and drive up pH toward respiratory alkalosis. The result is vascular constriction and unfriendly hemoglobin (where O<sub>2</sub> and NO are more sparingly released), and thus a radically reduced oxygen and glucose supply to body tissues in need, e.g., to the brain and to the heart.

### COMPROMISED RESPIRATION

“Taking charge of breathing” triggered by an unconsciously learned breathing habit, or brought on by a misguided conscious breathing intervention, often results in overbreathing and immediate changes in acid-base physiology as per the H-H equation. The result is hypocapnia (PaCO<sub>2</sub> deficit) and respiratory alkalosis (increased plasma pH). The rise in pH may trigger immediate and profound changes in physiology, some of which are listed in Table 1 (Hypocapnia: Physiological Effects).

The symptoms and deficits associated with the physiological changes listed in Table 1 can be profound, even devastating, and may include ones that are **physical** (e.g. brain fog), **emotional** (e.g., anger), **cognitive** (e.g., attention deficit), **personality** (e.g., sense of self), and **behavioral** (e.g., test taking) changes. Some of these symptoms and deficits are listed in Table 2 (Hypocapnia: Symptoms & Deficits).

The physiological changes listed in Table 1 can also **trigger** (e.g., epilepsy), **exacerbate** (e.g., asthma), and **prolong** (e.g., nausea during pregnancy) **symptoms and deficits** associated with numerous organic conditions. Some of these organic conditions are listed in Table 3 (Hypocapnia: Exacerbation of Health Issues and Complaints). These effects are all too often mistakenly attributed to other causes or are identified as “unexplained symptoms” in clinical literatures.

Overbreathing is the most common form of learned dysfunctional breathing affecting respiration in unencumbered healthy people, although underbreathing habits are occasionally seen. Learned underbreathing, when it does occur, is usually the result of hyperinflation, where people continuously abort their exhales, thus moving air in and out of anatomical deadspace and preventing inhaled air from adequately reaching the alveoli of the lungs where gas exchange takes place. That is, although the

breathing may be very fast, *alveolar ventilation* remains inadequate. As in the case of many dysfunctional habits, hyperinflation is usually associated with phobia about getting enough air coupled with faulty beliefs about breathing.

Some of the physiological effects of overbreathing on neurophysiology listed in Table 1 and their associated symptoms and deficits listed in Table 2, are briefly reviewed in the next section of this report from the perspective of their role in the effects of breathing on consciousness.

## RESPIRATION AND CONSCIOUSNESS

Overbreathing results in reduced CO<sub>2</sub> concentration (hypocapnia) and alkalosis in blood plasma, cerebrospinal fluid, and the interstitial fluid that surrounds all neurons in the brain. Hypocapnia results in cerebral vasoconstriction, as a function of its direct impact on vascular smooth muscle tissue, and compromised delivery of oxygen and nitric oxide on the part of hemoglobin as per the Bohr Effect in the red blood cells (less CO<sub>2</sub>, less hydrogen ions). The net effect is a potentially serious compromise of the delivery of oxygen (hypoxia) and glucose (hypoglycemia) to neural tissue. These compromises, along with the migration of calcium ions into smooth muscle tissue because of plasma alkalosis, can trigger vasoconstriction so significant that blood flow in the brain as a whole can be reduced by as much as 50 or 60 percent within less than a minute. It is this kind of change that can precipitate symptoms so severe that people call 911 for help (emergency ambulance service for transport to the hospital).

Respiratory alkalosis in interstitial and cerebrospinal fluids results in electrolyte changes that have profound effects on neuronal functionality. Sodium and potassium ions migrate into neurons, in exchange for hydrogen ions (H<sup>+</sup>) which increases their metabolism, excitability, and contractility. Unfortunately, this is taking place at a time when there is significantly reduced oxygen availability and thus hastens and exacerbates the onset of anaerobic metabolism in neurons where intracellular lactic acidosis then compromises neuronal functioning.

The basic outcomes of these changes in physiology thus include brain hypoxia (oxygen deficit), brain hypoglycemia (low blood sugar), and metabolic (lactic) acidosis in neurons, all of which can profoundly alter overall brain function. Besides unfortunate physiological outcomes (e.g., headache, ischemia, and the possible triggering of neurological syndromes), these outcomes can have immediate effects on attention, perception, motivation, emotion, cognition, learning, memory, personality, performance, sense of self, and consciousness.

Examples of psychological changes, from a downside perspective, include: emotional vulnerability, anxiety, anger, fear, panic, phobia, apprehension, worry, crying, low mood, dissociation, disorientation, dizziness, fainting, confusion, hallucinations, attention deficit, learning deficits, poor memory, brain fog, inability to think, low self-esteem, and undesirable shifts in personality. On the other hand, from a consciousness perspective these kinds of “negatives” can lay the groundwork for important “positives” through individualized guided breathing explorations.

The ways in which a specific person responds to these physiological changes are highly variable and are dependent upon health, life circumstances, personality, immediate social environment, and especially personal psychological history. For example, disorientation and dizziness, as a function of oxygen deficit, may trigger fear or anxiety in one person and relief or relaxation in another. These differences are based on unique personal histories involving specific experiences in specific situations.

State change and dissociation are key players in how people respond to breathing mediated physiological changes. Breathing-induced state change may serve the individual in both positive and self-defeating ways, much in the same way as do psychoactive substances that provide for access and experience of self, others, and the world from new, different, and sometimes revealing perspectives.

Intentional state change through overbreathing can set the stage for life altering and spiritual experiences, including uncovering and triggering traumatic memories that provide for working through painful episodes in life or for discovery of dysfunctional habits and their associated effects when triggered by specific places, times, people, tasks, emotions, thoughts, social circumstances, fatigue, challenges, and physical feelings based on personal histories.

Unintentional breathing-mediated state changes, brought on by dysfunctional habits, are common. These state changes can serve people in powerful and unique ways, outside of their awareness, based on a personal history that gives specific meaning to such changes. These state changes can be habit-forming in the sense that they may provide for avoidance of thoughts, emotions, and memories or access to a different and preferable sense of self (personality). State-dependent learning and memory, and their role in drug addiction for example, have been extensively researched in both humans and animals and are described in thousands of articles in numerous science journals.

### CONCLUDING COMMENTS

Anyone who does breathing work with clients should know at least something about the basics of respiratory physiology and how changing breathing mechanics immediately, profoundly, and precisely alters breathing chemistry. A truly practical understanding, however, of the dynamics of breathing physiology, how it is ultimately governed, how it affects us, and how we interact with it *requires knowledge of its psychology*, not just the details of its mechanics and chemistry.

Breathing mechanics and breathing chemistry weave together in a dance. In this dance, however, as we embrace the daily diverse circumstances of our lives, everyday-breathing should provide for the alignment of mechanics with chemistry in the service of health, performance, and consciousness. The “chemical axis” of breathing needs to remain within the optimal respiratory envelope, thus meeting oxygen, carbon dioxide, and acid-base balance requirements.

Everyone has learned breathing habits, positive and negative. Habits are solutions triggered by specific experiences (stimuli) that are sustained by their outcomes. That is, breathing not only serves respiratory requirements (external respiration), but very importantly serves a host of other behavioral and psychological objectives, most of them unconscious. Examples of conscious objectives include: talking, emotional control, relaxation, meditation, psychotherapy, consciousness exploration, and cultivating spiritual awareness. Examples of unconscious objectives include: accessing secondary gain (headache), feeling in control, accessing emotions (anger), anxiety reduction, avoiding memories, disconnecting, and many others. Unconscious objectives are achieved through learning breathing habits based on personal experiences. Everyone has them.

The relationship between breathing and respiration, mechanics and chemistry, cannot be fully appreciated without understanding the psychological nature of physiology itself. Breathing, like any other behavior, is motivated and changes as a function of its outcomes. Breathing isn't simply mindless automation of physiology. And, it isn't simply physiology to be somehow consciously manipulated in the name of self-help. It's truly so much more than this. Simply manipulating breathing physiology for well-intended purposes, without regard to the bigger picture, does not do justice to the richness and complexity of breathing.

Optimal breathing might best be expressed by the two images which define the Japanese word for breathing: HEART and SELF. Another way of seeing this might be: heart + self = presence. Breathing, in other words, may be a fundamental glue that holds the self and the heart together, making possible a greater personal presence for the world, others, and ourselves.

## **TABLE 1: HYPOCAPNIA (respiratory alkalosis, overbreathing)**

### **Physiological effects**

- Compromised O<sub>2</sub> distribution (hemoglobin)
- Compromised nitric oxide distribution (hemoglobin)
- Cerebral vasoconstriction (increased pH)
- Cerebral hypoxia, hypoglycemia, ischemia
- Increased neuronal excitability & contractility
- Neuronal acidosis (lactic acid)
- Sodium and potassium migration into cells (excitability)
- Hyponatremia (sodium deficiency, long term effect)
- Hypokalemia (potassium deficiency)
- Bicarbonate deficiency (long term kidney effect)
- Cerebral excitatory and inhibitory disturbances
- Stress hormone release (ACTH)
- Increased overall vascular resistance (smooth muscle constriction)
- Bronchial constriction (airway resistance)
- Reduced lung compliance
- Myocardial electrophysiology disturbances
- Coronary (vascular) constriction
- Gut smooth muscle constriction
- Calcium migration into muscle cells (fatigue, spasm)
- Release of excitotoxins such as glutamate
- Thrombosis, platelet aggregation
- Dishabituation
- Antioxidant reduction
- Tissue inflammation (systemic)

## **TABLE 2: HYPOCAPNIA (respiratory alkalosis, overbreathing)**

### **Symptoms and Deficits**

- Respiratory: shortness of breath, airway resistance, bronchial constriction, asthma symptoms
- Peripheral: tingling, numbness, trembling, twitching, shivering, coldness, sweatiness
- Cardiovascular: palpitations, tachycardia, arrhythmias, angina symptoms. ECG abnormalities
- Emotional: anxiety, anger, fear, panic, phobia, apprehension, worry, crying, low mood
- Autonomic-stress: acute fatigue, chronic fatigue, headache, muscle pain, weakness
- Sensory: blurred vision, sound seems distant, reduced pain threshold, dishabituation, dry mouth
- Consciousness: dissociation, state change, dizziness, fainting, confusion, hallucinations
- Cognitive: attention deficit, learning deficits, poor memory, brain fog, inability to think
- Muscles: tetany, hyperreflexia, spasm, weakness, fatigue, pain, difficult to swallow, chest discomfort
- Smooth muscles: cerebral, coronary, bronchial, gut, and placental vasoconstriction
- Abdominal: nausea, vomiting, cramping, bloatedness
- Movement: diminished coordination, reaction time, balance, perceptual judgement
- Performance: sleep apnea, anxiety, rehearsal, focus, endurance, muscle function, fatigue, pain
- Psychological: shifts in personality, self-esteem, memory, emotion, thought



**TABLE 3: HYPOCAPNIA (respiratory alkalosis, overbreathing)**  
**Exacerbation of Health Issues and Complaints**

- Neurological: epilepsy
- Cognitive: learning disabilities, ADD, ADHD
- Emotional: anger, phobias, panic attack, anxiety, depression
- Psychological: trauma, PTSD, drug dependence
- Vascular: hypertension, migraine, ischemia, hypoglycemia
- Cardiovascular: angina, heart attack, arrhythmias, ECG abnormalities
- Efficacy of drugs: shifts in pH and electrolyte balance alter absorption
- Fitness issues: endurance, muscle strength, fatigue, altitude sickness
- Gastric: irritable bowel syndrome (IBS), non-ulcer dyspepsia
- Respiratory: asthma, emphysema, COPD
- Chronic pain: injury, disease, systemic inflammation
- Pregnancy: fetal health, premature birth, symptoms during pregnancy
- Neuromuscular: repetitive strain injury (RSI), headache, orthodontic
- Sleep disturbances: apnea
- Psychophysiological disorders: headache, chronic pain, hypertension
- Behavioral: performance issues, speech, singing, task challenges
- Unexplained conditions: fibromyalgia, chronic fatigue