

Evidence-Based Role of Hypercapnia and Exhalation Phase in Vagus Nerve Stimulation: Insights into Hypercapnic Yoga Breathing Exercises

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Abstract

Being a yoga practitioner, Dr. Singh has always been curious to know of how yoga works. First, after going through the book—Nature and Health, he could find that carbon dioxide stimulates vagus nerve. Thereafter he could also find a study that shows of how increased blood concentration of carbon dioxide (hypercapnia) in conscious humans can stimulate the vagus nerve that in turn, manifests as respiratory sinus arrhythmia (RSA). Even more important, the results of this study also prove that when hypercapnia is coupled with exhalation phase, a synergistic effect occurs that compounds the cardio-inhibitory response of vagus nerve.

In some review articles, it was stated that increased blood CO₂ concentration is the most probable mechanism that determines an enhanced effect on the cardio-inhibitory response of vagus nerve during exhalation phase of the breathing rhythm.

In another very interesting study, the importance of exhalation phase of the breathing rhythm in superficial acupuncture stimulation was revealed. As the effect is comparatively pronounced when acupuncture stimulation is applied only during exhalation versus continuous stimulation during both inhalation as well as inhalation phase.

Since the above research studies clearly show of how “hypercapnia” and “exhalation phase” are the two most important determining factors for the stimulation of vagus nerve. Hence these research findings prompted the author to write this article that may further help yoga practitioners in controlling these important variables (blood concentration of carbon dioxide and exhalation phase) in an effective and efficient manner, on a moment-to-moment basis.

The author, in the sub-head “Insights”, describes about the importance of Carbon Dioxide and Exhalation Phase in stimulating the vagus nerve. Furthermore, he also explains in details about the two most important breathing exercises (Pranayama and Buteyko method) in the sub-head titled, “Hypercapnic Exercises”.

Keywords: Hypercapnia; Exhalation phase; Vagus nerve stimulation; Pranayama; Buteyko method

Introduction

This review article is basically designed and written in the hope that the findings of the above studies will ensure that individuals have the insights they need, to make sure their yoga practice easier and to improve their performance by controlling important variables, including carbon dioxide concentration and exhalation phase, on a time-to-time basis [1-4]. Since knowledge feeds performance, and knowledge is also derived from performance. Thus, knowledge and learning can form a closed loop.

Since yoga practices have been developed after long years of self-care and observation of one's own acts. Though literature notes a variety of yogic practices with different names, however, only traditional breathing techniques (i.e., Pranayama and Buteyko Method) are discussed in this review.

If these exercises are practiced regularly then, when stress response is elicited, it may not be as intense, and return to a balanced state will be faster. Research findings suggest that it is possible to alter, in a positive manner, the neurophysiology of the body, so that it returns to a more balanced state.

According to several clinical trials, yoga seems to confer many of the mental and physical benefits. Yet, for a long time, the scientific basis of yoga could have not been established in the past. Now, research by Wilson can explain how the practice of yoga could be of help in changing the tone and reactivity of the nervous system (especially the vagus nerve) to its positive value [5].

The results of this study would certainly allow the yoga practitioners to perceive and make possible for them to improve their techniques for stimulation of their vagus nerve [6].

Insights

The insights for yoga practitioners are as follows:

Why is Vagus nerve important?

The vagus is divided into two parts; the ventral vagal pathway and the dorsal vagal pathway. The ventral vagal pathway supports feeling safe and social. When we feel comfortable and connected our ventral vagal system is online and in charge [7]. On the other hand, the dorsal vagal pathway responds to signals of extreme danger. It takes us out of connection, out of awareness and into a protective state of collapse. When we feel frozen, numb, or “not here” the dorsal vagal system has taken control [8]. Porges's theory (The Polyvagal Theory) provides a missing link between mind and the nervous system [8].

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Merits of vagus nerve stimulation are as follows

- (i) The vagus nerves carry a wide variety of signals to and from the brain, and they determine various reflex responses that, in turn, control the body. It means that there is a connection between vagal tone, mental state and physical health. Stated otherwise, if you increase your vagal tone, your mental as well as physical health will improve [9].

Increased vagal tone helps combat stress through the manifestation of relaxation response that, in turn, calms the mind and relaxes the body [6].

- (ii) Short-term (acute) stress is, in fact, beneficial to our bodies. Since it help us adapt to our environment. Whereas Long-term (chronic) stress is harmful as it impairs the immune system. It is because our bodies are not designed for chronic stress. Remember, the vagus nerve is the key to regulating our immune system—one of the vagus nerve's functions is to readjust the immune system [10].
- (iii) Research shows that vagus nerve stimulation abates inflammation. Since vagus nerve is thought to mediate its anti-inflammatory function by secreting acetylcholine. Therefore vagal nerve stimulation can be utilized for the treatment of inflammatory diseases that have emerged as a result of chronic stress. Acetylcholine also plays an important function in attention, memory and learning [9].
- (iv) Studies have shown a positive correlation between vagal stimulation and release of neurotransmitter oxytocin. And higher levels of oxytocin, in turn, can promote large number of positive transformations in one's nature, i.e., sensing, feeling, thinking and acting. Alterations in these attributes include feelings of love, connectedness with others and above all a sense of contentment and peace within oneself [10].
- (v) Research has shown that vagal stimulation helps you not only in controlling the health of your organs and tissues, but it also determines the growth of your stem cells which, in turn, help body in repairing and replacing damaged cells [9].

In conclusion, Parasympathetic nervous system is called the “rest” and “digest” system. It conserves the body's energy and thus helps it return to homeostasis. During restful states, it is the parasympathetic limb of the autonomic nervous system that dominates [11].

“Do you have a sensitive nervous system that adversely impacts your health? By developing an understanding of the workings of your vagus nerve you may find it possible to work with your nervous system rather than feel trapped when it works against you. Fine tunes your self-care with vagus nerve regulation strategies that can be practiced in the comfort of your home” - Dr. Arielle Schwartz [10]. Conscious breathing is the key to stimulating your vagus nerve.

For a long time it has been a mystery of how involuntary functions change activity of the brain areas. Since the vagus nerve is the master nerve—an important connection between the brain and the body. It has been found that vagus nerve stimulation (VNS) therapies affect areas of the brain that are implicated in mood regulation. Still, further research is to explore more connections so as to comprehend the effects of VNS therapy in neuropsychiatric disorders [12].

Why exhaling matters most?

The benefits are as follows:

- (i) Slowing down breathing - Slowing down exhalation phase promote dominance of the parasympathetic system. Even more important, during prolongation of exhalation, accumulation of carbon dioxide in blood takes place. It is underappreciated fact that a certain amount of Carbon dioxide (CO₂) in blood is necessary for a good health. Since during stress we take small, shallow breaths and carbon dioxide is blown off. Hence, controlling your breathing pattern can help maintain appropriate levels of blood CO₂. It is a narcotic gas. Therapeutic increase of CO₂ will have a calming effect [13].

It is important to note that Tibetal lamas maintain their CO₂ levels raised by way of simply prolonging their exhalation phase during chanting [13]

- (ii) Breathe holding and grounding - Problem is that in modern times people habitually hold their breath in their inhalation phase that, in turn, creates anxiety and tension in the body. Research studies demonstrate that people under stress hold their breath in inhalation and when it becomes a habit they are caught in an emotional rut and then they feel ungrounded [14].

According to Porge's polyvagal theory, when we are firmly grounded in our ventral vagal pathway, we feel safe and connected, calm and social [8].

Grounded people seem well-balanced and aligned. They tend to be sure of their footing or hold on reality and remain open and responsive to any new input in their lives.

By restoring appropriate postural and breathing patterns one can improve their ability to authentically “ground.” An important component to this is to establish a full exhalation to allow the diaphragm to achieve a relaxed domed position in contact with the internal rib cage. It typically requires specific postural restoration technique so that the brain-body can learn a “grounded pattern.”

The only way of getting out of your emotional rut is that you bond and yield (surrender) to gravity during your exhalation phase of the breathing cycle. This would allow you to settle into a proper postural stance that, in turn, let you breathe freely.

We are always under the influence of gravity. Holding posture isometrically, in exhalation phase, is an excellent exercise for strengthening the core muscles and rehabilitation.

Once holding breath comfortably in exhalation phase is perfected, it becomes a natural self-care; an invisible, but vital skill. Even more important, with totally invisible relaxation, you can actually relax just anywhere you are—sitting or standing, walking or sleeping.

Since exhalation is the phase of relaxation. By holding posture in exhalation phase, we can activate our parasympathetic nervous system (PNS), thus increasing relaxation and allowing a number of benefits. However, for the long-term benefits of breath holding, we would require to stay frequently in parasympathetic dominance during our activities of daily living [15]. Holding of breath in a comfortable and adaptive manner allows us to retain appropriate blood levels of carbon dioxide [14]. Good news is that our respiratory centers can adapt to hypercapnia when we practice resistive breathing in a sustained and successful manner [16]. This type of breathing requires that we should attain a habit of controlling our breath most of the times in a spontaneous manner [17].

Yoga tradition maintains that we should restrain our breath twenty four hours a day, seven days a week; all time [18].

Did you know that a seasoned yoga practitioner can experience joy despite any sensory input and in any state of consciousness?

Carbon dioxide facts and myths

We are taught in our medical schools that oxygen is good and carbon dioxide (CO₂) is bad [19]. But fact is that a certain level of CO₂ in the blood is always required for maintaining a good health. Even more important, due to its Bohr's effect, CO₂ determines bioavailability of oxygen to the tissues and cells. As oxygen is the prime nutrient to every cell. Did you know that without CO₂, tissues will be starved of oxygen independent of its availability in the blood [14]?

Carbon dioxide is not always a final waste product. It may be used in molecular building of the material [17]. Hence, it is a serious error to consider carbon dioxide purely a waste product. In physiological concentrations, carbon dioxide acts like a hormone [20].

There are many benefits of carbon dioxide. Only the important ones mentioned are as follows:

- (i) Carbon dioxide produces a vagotropic effect. The direct influence of carbon dioxide cause changes in the sensitivity of the vagus nerves nuclei, which decelerate cardiac activity, particularly the diastolic phase (a shorter time for the contraction of ventricles and a longer time for their relaxation); this decelerates the pulse rate and improves the blood-filling of the heart [1].
- (ii) Carbon dioxide is the natural sedative and tranquilizer [18]. Since the narcotic effect of CO₂ is extremely therapeutic. It depresses the irritability of the centers of conscious perception or of voluntary movements. Carbon dioxide is very important for our brain. When we have CO₂, we have logic, common sense, reason. When we do not have it, we can experience panic attacks, we can be depressed, angry. This is possible when CO₂ is the factor of stability of our nerve system. Because of this very fact, CO₂ is called tranquilizer and sedative of brain.
- (iii) Carbon dioxide is the expert facilitator of respiration.
- (iv) It should be noted that by way of carbon dioxide assimilation body synthesizes carbon compounds to be utilized by the cells [21]. Carbon dioxide may serve as a metabolic substrate in such known reactions as "CO₂-fixation" and carbamate formation. The rate of incorporation of CO₂ is at least partially dependent upon pCO₂; therefore, any situation altering pCO₂ could conceivably affect the kinetics of such reactions. Consequently, the maintenance of a constant level of CO₂ is an important physiological function [22].
- (v) Carbon Dioxide concentration controls all aspects of Homeostasis in blood [23].

If carbon dioxide is so good for us, then we should increase the CO₂ level in our bodies. When you hold your breath, CO₂ gradually builds up on your blood, and when it builds to your tolerance level, your respiratory center gives you the urge to breathe. You can reduce your brain stem's sensitivity to CO₂ and thereby increase your usual level of carbon dioxide to supercharge your overall health [24].

Research shows that increase of CO₂ concentration within safe limits does not cause any harmful effect on the body [25].

In summary, carbon dioxide primarily controls acid-base balance and cardio-respiratory system [26]. "It will be seen that carbon dioxide

is truly the breath of life." "Carbon dioxide is the chief hormone of the entire body; it is the only one that is produced by every tissue and that probably acts on every organ."

Carbon dioxide and breathing

The principal chemical stimuli to breathe are a rise in blood concentration of carbon dioxide and a fall in pH.

Central chemoreceptors within the medulla respond to the hydrogen ion activity (H⁺) in the cerebrospinal fluid (CSF) and indirectly to changes of pCO₂ in the blood. The pH of the CSF remains remarkably constant despite marked changes in blood pH. The blood-brain barrier appears to be capable of actively transporting ions in such a way as to regulate the pH of the CSF.

Whenever the pCO₂ in the blood rises above the levels of about 40 mm Hg breathing is stimulated so that the excess is blown off. There is, therefore, a very sensitive feedback mechanism based on the level of the pCO₂ and hydrogen ion activity in the blood which ensures an appropriate depth of respiration for particular metabolic and environmental situations.

Peripheral chemoreceptors in the carotid and aortic bodies sense changes in the pCO₂ and pH of the blood and relay those reflexes to the respiratory center via the glossopharyngeal and vagus nerves.

It is estimated that 80% of the resting ventilator drive originates in the central chemoreceptors, whereas, 20% ventilatory stimulation comes from the peripheral chemoreceptors [27].

In conclusion, under normal conditions variations in the CO₂ tension alone control breathing. It should be emphasized that a level of ventilation sufficient to eliminate CO₂ in appropriate amounts is more than adequate to meet the oxygen requirements [28].

Yoga Breathing Exercises and Hypercapnia

Previous studies on relaxation-response techniques, such as meditation, yoga and prayer, have shown that eliciting the relaxation response — a physiologic state of deep rest — not only relieves stress and anxiety, but also affects physiologic factors such as blood pressure, heart rate, and oxygen consumption. Furthermore, transcendental Meditation is one of the techniques that have shown to bring the physiologic changes of relaxation response: decreased oxygen consumption; decreased carbon dioxide elimination; decreased rate of breathing [29].

When the body is organized in gravity, by way of integrating our exhalation phase with the making of our posture, which in turn supports breathing. As we feel ease within our posture then, physical and emotional stress diminish and we breathe less. It also allows us for holding the breath as long as it is comfortable. Thus, carbon dioxide (CO₂) is retained in the brain and arterial blood, on a time to time basis. When CO₂ concentration becomes critical, deep and prolonged inspiration follows.

It is amazing that simply stopping and breathing will do to alleviate stress and create a clear mental and emotional atmosphere in which to proceed. In effect, we must learn "not to breathe" in order to truly breathe in a new a different way [30].

Clinical Trials

The following research studies show how consistent practice of breathing techniques can help to increase blood concentration of carbon dioxide:

1. In one study conducted by Gersten et al. [31], tested the hypothesis that simple breathing exercises may significantly increase cerebral blood flow (CBF) and/or cerebral oxygenation. Eighteen subjects ranging in age from nineteen to thirty nine participated in the study during which measurements of end tidal CO₂ (EtCO₂ - by capnometer) and local brain oxygenation (by near-infrared spectroscopy (NIRS) sensor) were taken.

The participants were asked to do paced breathing exercises as instructed by the experimenters. They were asked to walk slowly, breathe in for 3 steps, hold their breath during the next 3 steps, exhale during the next 3 steps, and hold their breath for the next 3 steps after exhaling. People trained in breathing exercises may increase their PaCO₂ considerably by learning to control their tidal volume [31].

2. In another study conducted by Gersten et al. [32], tested subjects who could perform with a breathing rate of around 2/min or less. Six subjects were used who were experienced in yoga breathing techniques. They performed an identical periodic breathing exercise including periodicity of about 2/min. The results of all six subjects clearly show a periodic change of the cerebral blood flow (CBF) with the same period as the breathing exercises. Similar periodic changes in cerebral oxygenation were observed as well.

An evaluation of the cerebral blood flow (CBF) dependence on PaCO₂ was given by Gersten et al. [31,32]. It is important to note that the main parameter influencing the CBF is the arterial partial pressure of carbon dioxide (PaCO₂). About 70% increase in PaCO₂ may double the blood flow. The increase of blood flow to the brain results in an increase of nutrients and oxygen, which may influence to great extent brain's physiology.

3. Spicuzza et al. compared the response of ten experienced yoga practitioners (with average eight years of practice) with healthy controls who had never practiced yoga. Their data suggest that long term of yoga breathing independently reduces chemo reflex sensitivity as opposed to just slow breathing. They hypothesized adaptation of peripheral/central chemoreceptors to chronic CO₂ retention [33].

Hypercapnic Breathing Exercises

The goal of these exercises is to increase blood concentrations of carbon dioxide [17].

For most people, habitual (unconscious) holding of breath is a common feature during stress. We breathe in the chest and our breath becomes fast and shallow. When it becomes your habit, chances are that you may have been stuck in an emotional rut [34].

Chest breathing triggers sympathetic response and then our breath becomes fast and shallow. It causes a decrease of carbon dioxide in the blood [35].

Now we understand that if fast and shallow breathing can lead to reduced blood carbon dioxide (CO₂) concentration resulting in enhanced arousal and anxiety then, slow and deep breathing can be used in increasing blood CO₂ concentrations. There are numerous hypercapnic breathing exercises to increase CO₂ concentration. That is where (1) "Pranayama" and (2) "The Buteyko Method" comes in [18].

Pranayama - Mindful breathing

Though, we all breathe but we are not aware of the act of our breathing. Mindful breathing is a way of exercising greater control over your exhalation, exhalation, and pause. Mindful increases with practice. Mindful breathing helps us to remain in present moment.

Even more important, focusing on your own breathing can keep us from mental perturbations. Thus mindful breathing is a way to fight anxiety and stress.

Controlled exhalation helps us in getting into proper postural stance and then holding breath comfortably. Holding breath in exhalation, in turn, help us to breathe spontaneously during recovery inhalation. Remember, proper posture is an excellent preparation for pranayama [19]. When we are comfortable with our posture, breath slows down and there is a smooth transition between exhalation and inhalation, with a natural pause at the end of exhalation [36].

Though, holding of breath for a prolonged but comfortable period of time is an essential practice of pranayama. Yet, it should be initially avoided by novice practitioners [37].

We start with observation of our breath. When we become aware of all the three phases (exhalation, pause, and inhalation) of our breathing cycle, then only, you should try to extend your exhalation. It needs gentle curiosity and compassion [19]. We should concentrate on our exhalation phase only, as inhalation will take care of itself [37].

It is the known physiological fact that we cannot control our autonomic nervous system (ANS) directly. But, through the control of your breath you can regulate your ANS. Conscious breathing plays primary role in influencing your parasympathetic and sympathetic nervous system [38]. Did you know that your exhalation phase is the phase of relaxation? Extending exhalation is the way for inciting relaxation response—that is pranayama. Conscious breathing is a way of holding our breath either in sympathetic or parasympathetic mode of the autonomic nervous system activity [39].

Important: Efficient execution of exhalation is the basis for pranayama [40]. When transition between in breath and out breath becomes smooth then only we can hold our breath in an easy and comfortable manner.

If a subject holds breath at the end of a quiet expiration, he can maintain voluntary apnoea for a period of 45-55 s before reaching a "breaking point" at which the urgent desire to breath becomes dominant. Thus, holding the breath as long as it feels comfortable and controlled release when the desire to breathe becomes irresistible, determines the successful practice of pranayama. It is a popular concept of detoxifying and deceleration of the aging process.

When carbon dioxide works as a trigger for breathing, a breathing pattern with variability in its rhythm manifests that is appropriate and flexible according to the metabolic demands of the body on a time-to-time basis. It is a normal variation of breathing as found in infants less than one year. In infants respirations are not regular as they are found in adults. Infant often breathes deeply for a short interval of time and then breathes slightly or not at all for an interval, the cycle repeating over and over again — is it a normal condition.

Natural breathing, at physical and psychological rest, provides the minimum of breathing activity with a decrease in minute volume.

We can hold our breath, anywhere in between the end exhalation and inhalation phase of the breathing rhythm, with effort or in an automatic, natural and enjoyable manner. Since breath holding time is determined by the degree of relaxation. If we are in a relaxed state, we may prolong the pause between the exhalation and inhalation phase of the breathing rhythm.

You are advised to hold your breath for a period as long as it feels comfortable. It looks surprising but true that, a seasoned yogi can

hold his breath for about an hour or more in a comfortable manner—for building this much of capacity, it requires years of training with patience.

Benefits of breath holding:

1. To increase the O₂ absorption on the inhale and also to get the spine to extend.
2. Holding it for a moment creates muscle memory and allows for more O₂/CO₂ exchange.
3. By slowly moving into proper postural stance with each exhalation would provide opportunity for a tight muscle to relax. When we hold the stretch and breathe into it, it allows you to stretch further. Remember, muscle stretch stimulates breathing.
4. Holding of breath is a way of adapting to hypercapnia. It ensures adequate supply of blood to the brain [17]. “As you hold a pose, your prefrontal cortex is countering the raised sympathetic signal as it keeps you focused. As your mind learns how to do this even outside of the yoga room. Eventually with practice, you will be able to maintain self-control in most stressful settings” [41].
5. Breath holding with bandhas provides opportunity to maintain positive end expiratory pressure (PEEP) of above atmospheric pressure at the end of expiration. This improves ventilation-perfusion matching. The bandhas are first mastered by awareness. Without bandha control, “breathing will not be correct, and the asanas will give no benefit.” (Asthang Yoga)

It is interesting to note that during a comfortable breath hold, Oxygen is constantly absorbed through the alveoli from the air present in the airways and lungs [42].

Short-term and long-term benefits of breath holds: Short-term benefits include reducing stress and blood pressure and improving attention. In the long-term the practice of breath holds reduces psychological stress responses and improves cognitive functions by way of rewiring the brain circuits—you become open and responsive. Sustained and successful practice of breath holds reduces psychological stress responses and improves cognitive functions [43].

In summary, pranayamic breathing brings improvements in cognitive, emotional and social behaviors [44]. Research shows that slowing breathing is effective at reducing emotional arousal by activating parasympathetic nervous system [45].

Under physical and psychological rest, our brain subconsciously detects threat whether situations are safe or dangerous, that determines how to respond to the situation optimally [46]. Thus, prefrontal cortex is the area of the brain that is mostly involved in maintaining the body's homeostasis—it gives us the ability to come back to base line [47].

Buteyko Method

The Buteyko technique is mainly based on the principle of “breathing less” (similar to pranayama in relation to CO₂ increase) [18].

Regulation of breath is an important part of yoga practice. Controlled breath holds, in the beginning, have been shown to induce intense feeling for air. But, with practice, we can adaptively extend our breath-holding time [48].

Dr. Buteyko, a Russian physician and physiologist, developed a

technique for breathing less [48]. The Buteyko method provides a solid scientific explanation backed up with hundreds of clinical studies [48].

Dr. Buteyko has conducted a test called Control pause (CP) that shows the availability of oxygen to the tissues in the body. Measurement of CP is high in healthy individuals whereas sick people have low CP values indicates health [48].

Problem: Pranayama has been practiced for thousands of years in India [18]. But the fundamentals of pranayamic practices (the slowing down of breathing), have been forgotten or misunderstood by the western people [49].

All the main-stream health professionals must understand that whenever cardiorespiratory problem arises, respiratory therapists can help patients breathe easier [24]. The Complementary and alternative medicine is moving into the mainstream as more doctors integrate these therapies into practice [50].

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It is to declare that there is no issue of any kind of conflict of interest.

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