



TECHNIUM
SOCIAL SCIENCES JOURNAL

Vol. 28, 2022

**A new decade
for social changes**

www.techniumscience.com

ISSN 2668-7798



9 772668 779000

Conscious Breathing: a Powerful Tool for Physical & Neuropsychological Regulation. The role of Mobile Apps

Athanasios Drigas¹, Eleni Mitsea^{1,2}

¹Net Media Lab Mind - Brain R&D IIT - N.C.S.R. "Demokritos", Athens, Greece,

²University of the Aegean and Communication Systems Engineering Department, Samos, Greece

dr@iit.demokritos.gr, e.mitsea@gmail.com

Abstract. Breathing, although unconscious and often overlooked, is a central aspect of our whole being and one of our most vital functions. This review paper aims at investigating the physiological as well as the neuropsychological benefits of breathing training techniques. In addition, we examine the effectiveness of mobile breathing applications in upgrading human health and wellness. Finally, we discuss the role of metacognition in breathing, as the only means people have to gain awareness of the profound powers of breath and take conscious control of their health.

Keywords. breath-control practices, physiological & neuropsychological effects, awareness of breath, metacognition in breathing, attention to breathing, altered states of consciousness, regulation of breathing, regeneration, DNA restoration, anti-inflammatory status, longevity, (gameful) breathing apps, wearable mobile applications

1. Introduction

The human can live weeks without food, days without water but only minutes without oxygen. Often unconscious and overlooked, breathing is a central aspect of our whole being and is one of our most vital functions (CliftonSmith & Rowley, 2011). Breathing serves the purpose of respiration. Respiration could be simply defined as the exchange of oxygen and carbon dioxide between the organism and the environment via the cyclic act of ventilation. This cyclic exchange of gasses is responsible for maintaining tissue oxygenation and promoting a balanced state inside the body, also known as homeostasis (Jelinčić, Van Diest, Torta & von Leupoldt, 2021).

Oxygen is critical for proper metabolism on a cellular level, while carbon dioxide is crucial for achieving adequate pH levels (Brinkman, Toro & Sharma, 2020).

Ventilation mostly occurs automatically in a continuous rhythmic pattern without any conscious effort. It is controlled by both neural and chemical inputs and is concerned with the homeostasis of oxygen and carbon dioxide as well as having a role in the acid-base balance (Davies & Misra, 2014). In this process, several mechanisms are involved to ensure a rigorous balance between supply and demand (Brinkman, Toro & Sharma, 2020).

Breathing patterns reflect the functioning of the respiratory system and the biomechanical system as well as the cognitive state (CliftonSmith & Rowley, 2011).

Dysfunctional breathing generally describes deviations in the normal biomechanical patterns of breathing which have a significant impact on quality of life, performance and functioning (Barker, Thevasagayam, Ugonna & Kirkby, 2020). Inappropriate breathing patterns influence the pH balance (acid/alkaline) in minutes. Shallow breathing, for instance, causes an increase in carbon dioxide blood level and consequent respiratory acidosis. Rapid deep breathing washes out carbon dioxide from the blood increasing blood pH. On that account, respiratory adjustments play a major role in the acid-base balance of the blood (El-Nahas et al., 2019).

A disordered breathing pattern can be the first sign that all is not well, whether it be a mechanical, physiological, psychological, or cognitive dysfunction. Inappropriate breathing also can cause symptoms with no apparent organic cause or similar to diseases such as those of heart disease, panic or anxiety disorder (CliftonSmith & Rowley, 2011).

Common factors that affect breathing are the following: (a) *anthropometric factors* (weight, height, sex, and age), (b) *physical parameters* (circadian rhythms, chest diameter, trachea size), (c) *social and healthcare considerations* (educational level, socioeconomic status, workplace exposures), (d) *environmental factors* (air pollution, climatic conditions, natural disasters, altitude), (e) *lifestyle* (nutrition, level of physical activity, smoking), (f) *diseases* (diabetes, muscle or hormone disorders), (g) *physical position*, (h) *genetic factors* and even influencing factors occurring during childhood or pregnancy (Barroso, Martín, Romero & Ruiz, 2018; CliftonSmith & Rowley, 2011).

Due to the aforementioned reasons, many of the physiological functions related to breathing start to malfunction leading to the general degeneration of the body (Wu et al., 2017). With aging, for instance, breathing becomes shallower because of elastic recoil which enables, after inhalation, the lungs to automatically exhale. While the rib cage becomes tighter one needs to work harder on his/her inhalations to overcome a rigid elastic recoil and ultimately fill his/her lungs. In addition, when one slouches, the diaphragm becomes semi-contracted or pushed down resulting in the lungs' inability to fully expand (Colebatch, Greaves & Ng, 1979).

Shallow breathing leads also to chronic tissue hypoxia that has been linked to a variety of age-related health problems. Hypoxia and especially chronic hypoxia accelerates cell death as well as the proliferation of mutagenic stem cells. Shallow breathing also entails a dangerous imbalance between O₂ and CO₂, since one over-breathes oxygen and breathes out too much CO₂. (Colebatch, Greaves & Ng, 1979; Wu et al., 2017; CliftonSmith & Rowley, 2011).

Although hypoxic breathing has been a frightening term because of the possibility of damage to cells, tissues and organs, scientists now know that breathing is more complex than it seems. For instance, brief, episodic hypoxia can give rise to several adaptive responses. In many cases, therapists apply hypoxic therapy or various yogic breathing techniques that produce brief, intermitted hypoxia (Malshe, 2011).

A growing number of scientific studies especially in the field of contemplative neuroscience support the idea that breathing is at some degree under our control. Breathing techniques (i.e. Pranayama) aim at directly and consciously regulating internal bodily states by altering one or more parameters of respiration (Zaccaro et al., 2018).

Control of breathing pattern requires modification of the (a) *rate of respiration*, (b) *depth of respiration*, (c) *rate or velocity of airflow*, (d) *timing* (inspiratory and expiratory phase, duration, and pause), (e) the *rhythm of respiration*, and (f) *primary area of movement* (upper or lower chest, and abdomen). Either single or multiple modifications may be needed to get the desired effect on a case-to-case basis (Sankar & Das, 2018).

In ancient civilizations like Greece, India and Egypt breathing was well-recognized as a manifestation of life. Homer, Hippocrates, Empedocles, Plato, Aristotle, Galen developed

various theories about the role of breathing in human life recognizing that breathing participates in the highest levels of human existence. Nowadays, modern medicine makes great scientific discoveries about the mechanism of respiration, the role of breathing in health, and the ability of the human to use breathing as a tool for self-improvement (CliftonSmith & Rowley, 2011; Fitting, 2015).

For a long time, people underestimated the importance of proper breathing, since there was limited knowledge as well as education about the complex role of breathing in human health. However, the COVID-19 pandemic has put a sharp focus on breathing training opening a global discussion about the benefits on neuro-, psychophysiological levels as well as the importance of making breathwork a part of our daily routine (Divya, Bharathi, Somya & Darshan, 2021).

Smartphones and breathing applications provide novel opportunities to improve breathing training. Breathing training apps are always available to support users anywhere and at any moment. Moreover, the cost of a smartphone app is typically low, and it is relatively easy to find free apps. In general, smartphones are increasingly seen as a versatile m-health instrument for treatment and training and some authors predict that the mobile phone will emerge as the preferred personal coach for the 21st century. However, Mobile apps for breathing training lack formal evaluation in the literature (Chittaro & Sioni, 2014; Morris & Guilak, 2009). Another novel approach that has been explored for the delivery of health interventions except for mobile health (mHealth) is mHealth gaming. The “gamification” of mHealth apps engaging badges, leaderboards, points, levels, and challenges seem extremely promising, In addition, most applications use musical elements, which relax, motivate and facilitate the breathing experience (Pham et al., 2016, Theodorou & Drigas, 2017).

2. Method

The purpose of the current study is to investigate the physiological and neuropsychological benefits of breathing training. In addition, we examine the role of mobile applications as breathing training tools. The method used to write the article was the bibliographic review method. We searched articles through search engines: Google Scholar, Mendeley, PubMed, Scopus, Science Direct and ResearchGate. There was too much academic research regarding breathing techniques. In this study, we focused on the role of breathing training on physiological and neuropsychological aspects. One of the limitations of the research is that there is a lack of research studies assessing the effectiveness of mobile breathing applications in various aspects of human health.

3. Results

Article I. 3.1 Types of Breathing exercises

Warming exercises

Alternate nostril breathing: inhalation is done from one nostril while the other nostril is kept closed. It is based on the basic presumption that at a time only one of our two nostrils remains active. This breathing type cleanses our nasal tract and its continuation to the lungs. It protects from infections and oxygenates the blood properly. It also gives peace, calmness and good exercise (Dhaniwala, Dasari & Dhaniwala, 2020).

Kapalabhati is an advanced yogic diaphragmatic breathing technique that increases the lungs' capacity, oxygenates and energizes the person (Dhaniwala, Dasari & Dhaniwala, 2020).

Brastrika Pranayama: imitates the action of the bhastra or “bellows” and fans the internal fire heating the physical and subtle bodies. Inhalation and exhalation in this pranayama

are equal and are the result of systematic and equal lung movements (Budhi, Payghan & Deepeshwar, 2019).

Vase breathing: Research has revealed that breathing exercises could help subjects voluntarily increase their body temperature. “The *vase breathing*” is accompanied by isometric muscle contractions, where after inhalation, during a period of holding their breath (apnea), the practitioners contract both abdominal and pelvic muscles so that the protruding lower belly takes the shape of a vase or pot (Kozhevnikov, Elliott, Shephard & Gramann, 2013).

Right nostril breathing (Suryabheda pranayama) is traditionally described as “increasing the inner fire” and is believed to be heat-generating. This technique increases oxygen consumption, increases energy expenditure, activates the sympathetic nervous system, and elevates the body’s temperature (Telles, Gandharva, Gupta, Sharma & Balkrishna, 2020).

Cooling exercises

Sheetali and *Sitkari pranayamas* are traditionally recognized as breathing exercises that promote the process of cooling in terms of lower body temperature and a calmer mental state. During *Sheetali* breathing, inhalation is done through the mouth, while rolling the tongue into a semi-tubular shape. Expiration is done from both nostrils. (Gandharva, Gupta, Sharma & Balkrishna, 2020; Telles, Gandharva, Sharma, Gupta & Balkrishna, 2020). During *Sitkari* breathing, the upper and lower teeth are clenched together and the lips are drawn aside. Participants are asked to breathe in slowly and steadily through the gaps between the teeth. At the end of inhalation, participants close their mouths and exhale through the nose.

Relaxing breathing techniques

Diaphragmatic breathing: this type utilizes the diaphragm, which separates the chest cavity from the abdomen. This type of breathing causes the expansion and contraction of all the parts of both the lungs in all directions and is important for maintaining the vital capacity to the maximum. Diaphragmatic breathing has an impact on the brain and cardiovascular, respiratory, and gastrointestinal systems through the modulation of the autonomic nervous function. However, the effect of DB may differ depending on the severity of the disease. For instance, it could be harmful for dyspnea in patients with severe COPD (Hamasaki, 2020; Dhaniwala, Dasari & Dhaniwala, 2020).

Deep breathing: inspiration and expiration are repeated after longer intervals in each cycle making breathing patterns slow, long, and deep. It improves the vital capacity of the lungs and instills a feeling of calmness in the person (Dhaniwala, Dasari & Dhaniwala, 2020).

Bhramari Pranayama is a slow pace, breathing technique. It involves the slow exhalation from the nose with the mouth closed, after a deep inhalation, creating a humming sound from the closed mouth. It improves the autonomic system towards parasympathetic (vagal tone) dominance. It also boosts cognitive functions including inhibition and control, reduces irritability and stress (Kuppusamy et al., 2018).

Excitatory breathing techniques

Hold-breathing techniques: Breathing exercises based on the *Wim Hof method*, which is a combination of deep breathing and breath holds, increase arterial CO₂ concentration. (i.e., hypercapnia). Induction of hypercapnia before exercise is purported to elicit an acute sympathetic response, leading to an increase in excitatory hormones, tidal volume, and elevated blood flow to skeletal muscle in a manner that may improve endurance and exercise performance (Bahenský et al., 2020; Kox et al., 2014). *Fast breathing techniques*: inspiration

and expiration are done for a shorter duration in a fast manner (Dhaniwala, Dasari & Dhaniwala, 2020).

3.2 Breathing Training and Practice: The physiological & neuropsychological Benefits

Lung function, capacity & strengthening

Jansang, Mickleborough and Suksom (2016) investigated whether breathing exercises can improve lung function and respiratory muscle strength. Fifty-four older participants were divided into three groups: a) *diaphragmatic breathing*, b) *pursed-lips breathing*, and c) control group. The *pursed-lips breathing* using a windmill toy was more effective for improving lung function and respiratory muscle strength.

Budhi, Payghan & Deepeshwar (2019) observed the effect of *bhastrika pranayama* (bellows breath) on lung function of 30 healthy participants. The participants were assessed for (i) forced vital capacity (ii) forced expiratory volume in the first second (iii) peak expiratory flow rate and (iv) maximum voluntary ventilation functions of lungs. The results of the study concluded that the practice of *bhastrika pranayama* can recruit normally unventilated lung spaces and help strengthen the respiratory muscles and increase the elastic properties of lungs and chest, thereby improving its ventilatory functions.

Hakkeed, Balakrishnan & Krishnamurthy (2017) studied the effects of yogic breathing practices on lung functions of twenty-seven competitive swimmers. The experimental group practiced a set of breathing practices: sectional breathing (*Vibhagiya Pranayama*), yogic bellows breathing (*Bhastrika Pranayama*) and alternate nostril breathing with voluntary internal breath-holding (*Nadi Shodhana with Anchar kumbhaka*) for half an hour, five days a week for one month. In the breathing training group, there was a significant improvement in maximal voluntary ventilation, forced vital capacity and number of strokes per breath. The authors concluded that voluntary breath regulation practices help to enhance respiratory strength and endurance.

Oxygen-carbon dioxide regulation

According to Szulczewski (2019), training of *paced breathing* improves CO₂ homeostasis during a paced breathing task. The researcher investigated whether seven days of paced breathing at a frequency of 0.1 Hz (6 breaths/minute) improves CO₂ homeostasis in a total of 16 participants. Results showed that the drop in PetCO₂ during paced breathing at 0.1 Hz was significantly reduced indicating improved respiratory homeostasis.

Slow breathing can prevent hypoxia as well as hypercapnia. Spicuza et al. (2000) tested whether chemoreflex sensitivity could be affected by the practice of slow breathing. This study showed that yoga breathing decreased chemoreflex hypoxic and hypercapnic responses.

Sankar & Das (2018) conducted an updated literature search on the role of breathing exercises in the management of childhood asthma. They found that the breathing exercises primarily modify the pattern of breathing to reduce hyperventilation resulting in the normalization of CO₂ level, reduction of bronchospasm, and resulting breathlessness.

Acid-base regulation

Kox et al. (2014) trained 12 healthy subjects in the *Wim Hof method* which includes breathing techniques that require *cyclic hyperventilation* followed by *breath retention*. In the intervention group, these breathing techniques resulted in intermitted respiratory alkalosis and hypoxia. In other words, breathing techniques altered the ratio between oxygen and carbon

dioxide and as a consequence the acid-base balance. However, this change had positive consequences, since it was found that anti-inflammatory mediators were improved.

El-Nahas et al. (2019) examined the effect of *Buteyko breathing technique* on blood gases among 30 asthmatic patients (25-35 years). Asthma is strongly associated with respiratory acid-base disturbances and especially with elevated acidity. Blood gases determine the blood pH as well as the type of the acid-base imbalance. Buteyko technique uses breath retention exercises to control the speed and volume of the breath. Results revealed significant changes in arterial blood gases decreasing pH level and PaCO₂ values by 1.32% and 12.82% respectively while increasing HCO₃ and PaO₂ values by 12.39% and 8.85% respectively. These results indicate that training in proper breathing patterns positively influences the pH balance of the blood.

Oxidative stress, antioxidant status, inflammation & immune response

Bhattacharya, Pandey and Verma (2002) assessed the effect of *yogic breathing exercises* on oxidative stress. The experimental group consisted of 30 trained volunteers and an equal number of controls. The free radicals were decreased significantly in the study group. Yogic breathing exercises also improved the antioxidant status of the individual preventing many pathological processes.

Martareli, Cochioni, Scuri & Pompei (2011) found that breathing exercises enhance the antioxidant defense status in athletes following an exhaustive exercise bout compared to a quiet sitting control group. The authors, therefore, suggest that *rhythmic yogic breathing* can protect athletes from long-term complications of free radicals.

Sharma et al. (2003) investigated the effects of *Sudarshan Kriya (SK)*, a breathing technique that involves breathing in different rhythms on superoxide dismutase (SOD), catalase, glutathione and blood lactate levels in practitioners and nonpractitioners of SK. Blood samples of 10 practitioners of SK and 14 non-practitioners were analyzed. The results showed significantly lower levels of blood lactate and higher levels of SOD, glutathione and catalase in practitioners as compared to nonpractitioners, suggesting a better antioxidant status after breathing training.

Sharma et al. (2008) continued their study with 42 SK practitioners and 42 normal healthy controls to evaluate the effects of breathing training on the gene expression both at RNA and protein levels of the genes. It was revealed that training helped subjects in overcoming oxidative stress by increasing the antioxidant enzymes in the body. Breathing training prolonged

the life span of lymphocytes by up-regulating the anti-apoptotic genes and pro-survival genes. Taken together, these results suggest that SK-practicing subjects are resistant to oxidative stress and show a higher level of protection from neurodegeneration, aging and cardiovascular diseases.

Buijze et al. (2019) examined the anti-inflammatory effect of breathing techniques along with concentration and exposure to cold on adults with axial spondyloarthritis, a type of inflammatory disease. The breathing techniques consisted of two exercises. First, patients were asked to hyperventilate for an average of 30 breaths. Subsequently, the patient exhaled and held their breath in an unforced manner for ~2–3 min until they felt a stimulus to inhale (“retention phase”). Breath retention was followed by a deep inhalation breath, which was held for 10 s. Subsequently, a new cycle of hyper/hypoventilation began. After the last cycle, patients were instructed to do strenuous exercises such as push-ups. The induced state of intermittent respiratory alkalosis and hypoxia typically “empowered” the patient to outperform their

standard capability in any physical exercise. The second breathing exercise consisted of deep inhalations and exhalations in which every inhalation and exhalation was followed by breath-holding for 10 s, during which the patient tightened all his body muscles. The research revealed a reduction in inflammatory markers in the experimental group (n=13) compared with the control group (n=11).

Kox et al. (2014) evaluated the effects of a training program on the sympathetic nervous system and immune response. Twelve healthy participants in the intervention group were trained for days in breathing techniques including cyclic hyperventilation followed by breath retention. Subjected were also injected with an endotoxin. In the intervention group, plasma levels of the anti-inflammatory mediators were 200% higher, while pro-inflammatory were 50% lower. Acute activation of the sympathetic nervous system intermitted respiratory alkalosis, hypoxia and norepinephrine played a crucial role in these results. The authors concluded that through practicing breathing techniques, individuals can voluntarily control their autonomic nervous as well as the immune system.

Kochupillai et al. (2005) evaluated the effectiveness of *Sudarshan Kriya* and *Pranayam rhythmic breathing* processes on immune functions. It was found that both breathing techniques significantly increased participants' natural killer cells.

Nisshesha rechaka pranayama offers benefits in defense mechanisms through brief intermittent hypoxia. Hypoxia induces the enzyme Nitric Oxide Synthase (NOS). Nitric oxide has been assigned different roles in different tissues. Widely, it is one of the defense mechanisms against oxidative damage. Thus more nitric oxide can protect the tissues better. In addition, induces p53 "Guardian of the genome", which is a transcription regulation factor and it has a protective role in DNA damage. These techniques also help stem cells to survive. (Malsh, 2011).

Growth, neurotrophic & neuro-synaptic factors

Intermitted hypoxia breathing training is shown to increase circulating brain-derived neurotrophic factors. Helan et al. (2014) examined the effect of hypoxia on BDNF secretion. Analysis of circulating BDNF in 30 healthy human volunteers showed that 72h exposure to high altitude hypoxia resulted in higher BDNF compared to samples taken at sea level. Similarly, Vermehren-Schmaedick et al. (2012) found that acute intermitted hypoxia induced a significant increase in BDNF protein. However, Becke et al. (2018) found that normobaric hypoxia over two weeks reduced BDNF plasma levels in 28 young adults. These results indicate that hypoxic breathing has a significant effect on neurotrophic factors. The features of the intermitted hypoxia protocol (i.e severity, duration of exposure, duration of hypoxic episodes) might determine whether hypoxia triggers detrimental or therapeutic effects (Navarrete-Opazo and Mitchell, 2014). Zhu et al. (2010) found that hippocampal neurogenesis was enhanced by hypoxia, possibly because intermitted hypoxia stably boosted the expression of BDNF in the hippocampus. Intermittent hypoxia therapy through breathing techniques like *Nisshesha rechaka pranayama* leads to the formation of growth factors, such as the VEGF, and this leads to the formation of new blood vessels (angiogenesis) (Malshe, 2011).

Hormonal regulation

Martarelli et al. (2011) investigated the effects of a breathing control exercise, namely *diaphragmatic breathing* on exercise-induced oxidative stress and the putative role of cortisol and melatonin hormones. Sixteen subjects were divided into two groups, the diaphragmatic breathing group, and the control group. The results showed that breathing exercises reduced

cortisol and increased melatonin. Cortisol is inversely proportional to melatonin. Elevated cortisol inhibits melatonin production. The data also revealed that voluntarily breathing control training increased levels of plasma antioxidant markers indicating a higher antioxidant status and consequently lower oxidative stress and fewer free radicals. The researchers outlined the significant role of melatonin since it is considered one of the strongest anti-oxidants with positive effects on inhibiting free radicals and pro-oxidative enzymes, preventing oxidative damage, and repairing DNA. It also plays a crucial role in sleep, mood, and homeostasis restoration. Thus, it is obvious that people can voluntarily boost their balance and reverse neurodegeneration (Galano, Tan, & Reiter, 2018).

Ma et al. (2017) aimed to investigate the effect of *diaphragmatic breathing* on cortisol responses to stress. Forty participants were randomly assigned to either a breathing intervention group or a control group. The breathing group received intensive training for 20 sessions, implemented over 8 weeks, employing a real-time feedback device, and an average respiratory rate of 4 breaths/min, while the control group did not receive this treatment. The results showed that the breathing group had a significantly lower cortisol level after training, while the control group showed no significant change in cortisol levels. In addition, the researchers observed improved attention and mood.

In a randomized control trial, Vedamurthachar et al. (2006) examined the effects of *rhythmic breathing training* on stress hormone cortisol, adrenocorticotropic hormone (ACTH), and prolactin in a total of sixty participants (age 18-55 age). The intervention program consisted of three distinctive breathing periods: 1. *Slow deep breathing* (breathing in, holding, breathing out, and holding). 2. *forced inhalation and exhalation* 3. *slow, medium, and fast cycles of breathing*. Breathing exercises reduced cortisol and ACTH and increased prolactin. These results indicate the anti-stress as well as antidepressant effects of breathing training.

Kox et al. (2014) found that breathing techniques that include hyperventilation followed by breath retention provoke acute activation of the sympathetic nervous system as well as norepinephrine release in therapeutic levels.

Shukla et al. (2005) found that *hypoxic breathing training* results in the regulation of hormones that are responsible for appetite regulation and energy balance namely, leptin and ghrelin. Specifically, it was found that hypoxia reduced the hunger hormone (ghrelin) while it increased the leptin which is responsible to inhibit hunger.

According to Jerath, Crawford, Barnes and Harden (2015) breathing regulation techniques inhibit the mechanisms of anxiety stimulating the vagal activation of gamma-aminobutyric acid pathways in the brain which brings a sense of calmness.

Thermogenesis & Thermoregulation

G-tummo meditators mysteriously can dry wet sheets wrapped around their naked bodies during a frigid Himalayan ceremony. Kozhevnikof et al. (2013) found that *vase breathing* combined with visualization significantly increased body temperature. Reliable increases in axillary temperature from normal to slight or moderate fever zone (up to 38.3°C) were observed among participants only during the *Forceful Breath*. The findings indicated that there were two factors affecting temperature increase. The first was the somatic component which caused thermogenesis, while the second was the neurocognitive component (internalized attention on visual images) that aided in sustaining temperature increases for longer periods. The researchers concluded that *vase breathing* might help non-meditators learn how to regulate their body temperature, which has implications for improving health and regulating cognitive performance.

Suryabhedha pranayama is traditionally described as “increasing the inner fire” and is believed to be heat-generating. It is associated with increased sympathetic nervous system activity and increased energy expenditure. Telles et al. (2020) aimed at determining whether the surface body temperature would increase after *Suryabhedha pranayama* practice compared with sitting quietly for the same duration as a control. The participants were instructed to close their left nostril and inhale slowly and deeply through the right nostril. At the end of inhalation, participants were asked to close both nostrils and lower their heads to perform two physiological locks while holding their breath. The axillary surface body temperature increased after both experimental sessions of *Suryabhedha pranayama* practice. These results do not support the speculation that *Suryabhedha pranayama* may be a heat-generating practice.

Telles et al. (2020) aimed at recording the surface body temperature before, during, and after the performance of breathing exercises that are traditionally described as cooling such as *sheetali pranayama* and *Sitkari pranayama*. Seventeen healthy volunteers were assessed in 4 sessions: *sheetali pranayama* and *sitkari pranayama*, breath awareness, and quiet lying. However, the results showed that body temperature increased significantly during *sheetali* and *sitkari* while it decreased after breath awareness.

Autonomic nervous system regulation

The practice of breathing exercises like *pranayama* is known to improve autonomic function by changing sympathetic or parasympathetic activity. In a clinical trial Pal, Velkumary and Madanmohan (2004) found that *slow breathing* increased parasympathetic activity while decreasing sympathetic activity. In addition, they concluded that systematic breathing training helped people to improve and have better control of their autonomic functions in general.

According to Komori (2018), autonomic nervous activity is affected by breathing speed. Specifically, it was found that during *prolonged expiratory breathing*, the parasympathetic nervous function was significantly activated. Conversely, during *rapid breathing*, the parasympathetic nervous function was significantly suppressed.

In a randomized control trial, Mourya, Mahajan, Singh & Jain (2009) investigated the effects of *slow-* and *fast-breathing exercises* on autonomic functions. Sixty participants were divided into three groups: a) slow breathing group, b) fast breathing group respectively and the control group. After three months, the results showed that both types of breathing have the potential to improve the autonomic nervous system. However, slow breathing brought better outcomes. Thus, the authors concluded that breathing regulation is likely to bring beneficial alterations in the autonomic responses.

Specific nostril breathing is known to influence autonomic functions. Pal et al. (2014) assessed the effects of *right nostril breathing* and *left nostril breathing* on heart rate variability (HRV) and cardiovascular functions. Eighty-five students were divided into three groups: the right nostril breathing group ($n = 30$), the left nostril breathing group ($n = 30$), and the control group ($n = 25$). Following 6-week practice, the results showed that there was sympathetic activation in subjects who practiced right nostril breathing and parasympathetic activation in those who practiced left nostril breathing.

Telles, Nagarathna and Nagendra (1994) investigated whether breathing exclusively through one nostril may alter the autonomic functions and whether breathing is consciously regulated. 48 subjects (aged 25 to 48 years) were randomly assigned to three different conditions: (a) *right nostril breathing*, (b) *left nostril breathing*, or (c) *alternate nostril breathing*. The '*right nostril*' group showed a significant increase of 37% in baseline oxygen consumption, whereas repeated breathing through the left nostril alone, or alternate nostrils

produces a smaller increase (24% and 18 % respectively). This increase in metabolism could be due to increased sympathetic discharge to the adrenal medulla. The 'left nostril Pranayama' group showed an increase in volar galvanic skin resistance, interpreted as a reduction in sympathetic nervous system activity. The researchers concluded that breathing selectively through either nostril could have a marked activating effect or a relaxing effect on the sympathetic nervous system. In other words, we can voluntarily influence our autonomic functions.

Laborde et al. (2021) investigated the influence of the inhalation/exhalation ratio and a respiratory pause on Cardial Vagus Activity (CVA) during slow pace breathing. CVA is an indicator of how efficiently self-regulatory resources are mobilized and used. The findings showed that CVA is higher when the exhalation phase lasts longer than the inhalation phase. The authors concluded that a longer exhalation provokes a longer activation of the parasympathetic nervous system, which is reflected in CVA. They also outlined that these findings are in line with the hypothesis that inhalation is driven by sympathetic nervous activity and inhibits parasympathetic nervous activity, while exhalation reactivates parasympathetic nervous activity.

Brain waves

Brain oscillations reflect the current state of consciousness. Recent studies reveal that voluntarily breathing control may alter these brain oscillations to reach the state of consciousness required to achieve our goals. Komori (2018) investigated the effects of a breathing method known as *Okinaga* on brain waves and autonomic nervous system function. According to this *deep breathing technique*, individuals perform extreme prolongation of expiration breathing. The results showed that theta and alpha 2 waves (9-11 Hz) increased and beta waves decreased. As a consequence, parasympathetic dominance was observed as *Okinaga* progressed. These findings suggest that deep breathing increases the brain waves of relaxation and resilience.

Bing-Canar, Pizzuto and Compton (2016) investigated whether engaging in a *mindful breathing* exercise would affect EEG oscillatory activity associated with self-monitoring processes. Forty-four participants undergraduate students were divided into two experimental conditions, mindfulness and control. Participants in the mindfulness condition engaged in a Mindfulness of Breathing audio exercise focused on attending to breath and being mindful in the moment. The results showed that breathing exercise increased overall alpha power during the exercise itself with a significant impact on self-monitoring during the subsequent Stroop task. The increase in alpha power reflects a mental state that is relaxed or characterized by an inward focus of attention. These results indicate that even brief breathing intervention enhances alpha waves boosting attentional control and self-regulation.

In a cross-sectional study, Malhotra et al. (2021) examined the effect of slow and deep respiration on EEG activity in experienced Yoga practitioners. The results showed that the Delta percentage decreased and the other wave's percentages theta, alpha, and beta increased significantly. The subject became deeply relaxed and more focussed on slow and deep breathing.

Gamma brain waves are the fastest brain waves produced inside your brain. Braboszcz et al. (2017) compared practitioners of three different meditation traditions (*Himalayan Yoga, Vipassana and Isha Shoonya*). The results showed increased gamma brainwave activity. Most important, it was revealed that people who focused on their breath experienced even greater

increases in gamma wave production than they did during the meditation part of their practice. These results indicate that attention to breathing increases the brain waves of alertness.

Thanalakshmi et al. (2014) investigated the impact of two cooling breathing techniques, namely *Sheetali* and *Sheetkari pranayama*, on an electroencephalogram. Twenty volunteers were divided either into the yoga breathing group or non-yoga breathing. The mapping revealed an increase in the delta and alpha band power in the frontal and occipital regions and an increase in theta band power in the frontal region with a marked decrease in beta band power almost throughout the entire hemisphere after two months' of *Sheetali* and *Sheetkari pranayama* practice indicating that the brain (mind) was calm and quiet in a relaxed state with less anxiety.

Attention & Consciousness

According to Melnychuk et al. (2018), respiration and attention constitute a coupled dynamical system characterized by physiological and functional overlaps. Fluctuations of the breath and attention are intimately interrelated and bi-directional phenomena. Each time respiration is disturbed, the attention becomes disturbed. Each time one controls respiration, he/she gets steadiness of attention. The researchers presented original findings according to which attention and respiration are coupled via the locus coeruleus, a small blue bilateral nucleus in the pons which is the main source of cortical noradrenaline and plays a significant role in respiration as well as arousal. According to their findings locus coeruleus, neurons exhibit chemosensitivity to CO₂ levels. Thus fluctuations in CO₂ levels provoke alterations to locus coeruleus which fire in sync with respiration and attention. Thus, breath-focused practices which require attention, observation, and awareness of the breath can modulate the nature of this coupling, achieve stability as well as synchronicity between attention and respiration. This synchronicity subserves perceptual binding, and most importantly, gives access to consciousness.

Zelano et al. (2016) found that the rhythm of breathing coordinates electrical activity across a network of brain regions such as the hippocampus and amygdala associated with attention, memory, emotion, and consciousness. Surprisingly, it was revealed that synchronization was higher immediately after breath in. In addition, they observed that participants could better identify fearful faces and recall images while breathing in. These results indicate that during inspiration there was not only better synchronization between hippocampus and amygdala but also better attention, memory, and consciousness.

Altered states of consciousness

Holotropic breathwork is a therapeutic breathing technique that produces altered states of consciousness. Holotropic Breathwork™ involves hyperventilation, a voluntary, prolonged, mindful, and deep over-breathing procedure. By breathing at a fast rate, the practitioners aim to voluntarily change the balance between carbon dioxide and oxygen. Miller, T., & Nielsen, L. (2015) conducted a pilot study to investigate whether and how this technique contributes to the development of self-awareness. A total of 20 participants participated in this study. The results for the more HB-experienced group primarily show character changes because there were positive significant changes at pre–post-test on the character scale self-transcendence. The increase in self-transcendence indicates that people develop higher spiritual awareness.

Hypoxia, depending upon its magnitude and circumstances, evokes a spectrum of mild to severe acid-base changes ranging from alkalosis to acidosis (Swenson, 2016). Episodic hypoxia not only can produce acidosis but also can have a major impact on consciousness. Hypoxic breathing can lead people to experience altered states of consciousness, even to the

loss of consciousness (Bickler et al., 2017). The intentional acute *starvation of oxygen* through hypoxia can shift consciousness to a euphoric state and leads to transcendental experiences. However, it carries a serious risk of accidental risk (Chater, 2021). *Nisshesha rechaka pranayama*, a breath-holding technique, is the simplest technique to produce intermitted hypoxia (Malshe, 2011).

Vialatte et al. (2009) utilized *Bhramari Pranayama*, a technique of breathing control with hypnotic aspects, which involves producing a vibrating sound while exhaling strictly through the nasal airways. After the start of the exhalation, the EEG of all subjects exhibited a dramatic increase in the power of high frequencies. Specifically, it was observed a particular pattern of EEG activity, which they called “paroxysmal gamma wave”. The subjects reported a feeling of peacefulness, blissful mental quiescence, described as a state in which thoughts are absent but the consciousness remains. The authors argued that this activity might represent a nonepileptic hypersynchrony activity.

Resilience

The COVID-19 pandemic has created unprecedented challenges for people globally, especially for those working in healthcare. Divya, Bharathi, Somya and Darshan (2021) aimed to investigate the impact of *Sudarshan Kriya Yoga*, a controlled cyclic rhythmic breathing technique, on depression, anxiety, resilience and life satisfaction. Ninety-two subjects participated in a 4-day online breath workshop. The results indicated that breathing training had a positive impact on subjects’ well-being. Participants experienced improved quality of sleep, enhanced satisfaction with life, and increased resilience.

Chandla et al. (2013) examined the effect of *Bhastrika* and *Anulom Vilom Pranayam* on heart rate variability, general well-being, cognition, and anxiety levels of ninety-six students. The results showed pranayama contributes to a significant increase in high-frequency components of heart rate variability and a decrease in low-frequency components. Higher heart rate variability constitutes a marker of the body’s resilience and self-regulation, while low frequency reflects the opposite.

Longevity

Wu et al. (2017) conducted a cohort study to investigate long-term surviving patients with cancer who practice *morning breathing exercises* daily. 76 respiratory patients performed morning breathing exercises, while 46 patients in the control group did not perform exercises. The five-year survival rate for the experimental group was 56%, while for the control group it was only 19%. The 10-year survival rate for the experimental group was 17 times greater than the control group. Interestingly, it was found that the increase in survival rate was linked to an increase in end-tidal breath holding time, which measures the improvement in alveolar O₂ pressure and alveolar CO₂ pressure capacity. In other words, longevity rates increased when participants could increase their ability to hold their breath after exhalation.

While chronic hypoxia contributes to aging, a lack of oxygen in small doses (via hold breathing) can trigger a rejuvenating effect known as intermittent hypoxia. According to Li et al. (2017), hypoxia can alter the expression of aging-associated genes and thus promote longevity. Specifically, they found that older people living at the Tibetan Plateau tend to have a longer lifespan than older people living at lower altitudes, suggesting an association between hypoxia and longevity in Tibetans.

Nakada et al. (2017) found that hold-breathing can induce heart regeneration. When they exposed mice to low oxygen tension for over two weeks, they observed that, in hypoxic mice,

there were a greater number of heart cells and the hearts were larger. The gradual reduction of inspired oxygen downregulated mitochondrial metabolism and ROS production in adult cardiomyocytes. Functional recovery in mice with myocardial infarction was significantly better in hypoxic animals. These results demonstrate that the endogenous regenerative properties of the adult mammalian heart can be reactivated by breathing exercises and highlight the potential therapeutic role of hypoxia in regenerative medicine.

Stem cells have become the foundation stone of regenerative medicine. Stem cells have the enormous capacity to differentiate into virtually any kind of cell in our body. Stem cells are abundant in fetal circulation where the partial pressure of oxygen (pO₂) is low. A young individual has also an abundance of these stem cells. However, the stem cell population reduces with age and is associated with various neurodegenerative disorders. *Nisshesha rechaka pranayama*, a hold-breathing technique that produces hypoxia can help stem cells to survive (Malshe, 2011).

3.3 Breathing education & training: The role of mobile breathing applications

Chittaro and Sioni (2014) evaluated three different designs for breathing training apps. The first employed audio instructions, while the other two included visualizations of the breathing process. Applications that use visualization may display a circle (or a sphere) that expands and contracts equally with the expansion and contraction of human lungs during the breathing activity. The results showed that breathing training apps can effectively improve the breathing process. Most important, the researchers found that applications that utilize visualization produce better results both objectively (measured deepness of breath) and subjectively (users' preferences and perceived effectiveness). Thus, breathing training apps could help users to overcome hyperventilation and the effects of fast and shallow breathing that may result in symptoms of intense anxiety and panic.

Bruggeman and Wurster, S. W. (2018) presented a virtual reality stress reduction mobile application that acts as a teaching tool for breathing training by utilizing real-time biofeedback. It is designed to attain and maintain the user's attention towards the breathing practice. The virtual experience begins by having the user strap a pressure sensor around their waist. This sensor is connected to an Arduino board and breadboard that transmit the data received from the pressure sensor to the mobile application via Bluetooth. This information is then processed into the digital application and provides biofeedback in the virtual environment. The user places the phone inside their mobile headset of choice and runs the application. This brings the user into the virtual healing space where he/she can get comfortable and begin. During the experience, the user slowly soars around a large tree by looking in the direction they want to fly. For instance, when users take a deep breath, they experience a small gust of wind on their backs in the virtual world.

"Foqus" constitutes an app running on a smartwatch to aid adults with attention deficits to improve focus and reduce anxiety through breathing training. Specifically, this app provides timed and haptic cues which guide users on regulating their breathing. Users can adjust the inhale/exhale cycle duration for deeper meditation. Users are presented with the average heart rate before and after the session as an objective measure of its effectiveness. This instant feedback on the quality of the completed session coupled with a visualization of progress is designed to improve the user's motivation and effort. To evaluate the usability of Foqus, a working prototype was developed on the Samsung Gear 2 smartwatch. Ten participants with

attention deficiencies were asked to perform breathing tasks for 7 days. 80% reported reduced levels of stress after each meditation session (Dibia, 2016).

Walsh, Saab, and Farb (2019) investigated the effectiveness of a mindfulness training app called Wildflowers on improving users' ability to identify internal physiological processes. Besides other techniques, Wildflowers includes breathing training providing didactic content in the form of lessons and information about the benefits of appropriate breathing. In addition, the app collects users' ratings of current mood and stress level as well as heart rate, before and after each session. This feedback is provided to the user with helpful insights into the physiological and psychological benefits of breathing training. In this study, undergraduate students completed 3 weeks of training with Wildflowers (n=45) or 3 weeks of cognitive training with a game called 2048 (n=41). Participants in the Mindfulness training group demonstrated better mood, reduced stress, and greater improvements in self-regulation.

In a randomized experiment, Chelidoni et al. (2020) evaluated the effectiveness of a brief app-based breathing intervention in enhancing physiological recovery among 75 employees who were induced to cognitive and emotional stress. This study examined Heart Rate Variability (HRV) changes which is a measure of the autonomic nervous system and a prominent biomarker of cardiovascular health. HRV indicates self-regulation strength, affective stability, and physiological adaptability. The BioBase app provided guided breathing according to participants' heart rate. In this study, participants in the BioBase breathing condition performed a 5-min guided diaphragmatic breathing exercise including attention on breathing, usage of the full lung capacity, a decrease of breathing rate to trigger vagus nerve and lead to the desired relaxation response. The results showed that there was a significant difference between the app-based intervention group demonstrating higher HRV compared with the control group. The authors concluded that biofeedback breathing interventions digitally delivered through a commercially available app can facilitate stress recovery and bring various positive health outcomes. Most importantly, these apps enable individuals to learn how to change their physiological activity to improve health as well as cognitive performance.

Equally, Plans et al. (2019) examined whether an app-based brief relaxation intervention could accelerate physiological recovery after a brief psychological stressor. A total of 75 participants completed a stressor speech task and were randomly assigned to one of three conditions: control, rumination, or app-based relaxation breathing conditions. Heart rate variability (HRV) was assessed at baseline, during stress, and during recovery. The results showed that the breathing application brought better outcomes in terms of interbeat intervals and high-frequency HRV than the other conditions. These findings provide evidence of the utility of biofeedback breathing in augmenting physiological recovery and suggest that app-based breathing interventions are effective in reducing cardiovascular disease risk.

Faust-Christmann et al. (2019) developed an app named 'Breathing-Mentor' which combines effective visualization of the instruction with biofeedback on deep abdominal breathing, based on the mobile phone's accelerometers. This pilot study aimed to investigate 39 users' feedback and breathing behavior during initial contact with the app. The results showed an increased signal-to-noise ratio for instructed breathing frequency reflecting the ability of participants to correctly follow the instructions provided by the app. This result supports the feasibility and usefulness of biofeedback in mobile breathing apps based on the mobile phone's accelerometers, especially for people who are unfamiliar with breathing techniques.

Lukic et al. (2021) evaluated the effectiveness of a new mobile gameful breathing training app in terms of physiological responses and users' feedback. The researchers

understood that breathing training applications should be more interactive and gameful to foster relaxation along with intrinsic motivation, narrative engagement, and enjoyment. Their design aimed at increasing experiential value through game elements that would not disrupt relaxation. In addition, they recognized the added value of colors as a means to boost relaxation and willingness for exploration, the cultivation of a feeling of progression during the session as well as exposure to natural environments. Afterward, a pilot study was conducted to assess how the app was perceived and whether it reached a physiological response comparable with that of the standard breathing training. The results yielded overall positive qualitative feedback. In addition, physiological measurements showed that gameful breathing training apps can guide participants to follow a predefined breathing pattern and raise their HRV and, thus, trigger health benefits. Finally, the use of richer graphics and game elements led to an increased experiential value and potentially improve engagement (Lukic, Reguera, Cotti, Fleisch & Kowatsch, 2021).

Lucic et al. (2021) conducted a similar study with an online experiment and 170 participants to assess the impact of breathing training, guided by a gameful visualization, on perceived experiential and instrumental values and the intention to engage in such training. The gameful visualization was found to increase the intrinsic experiential value of the breathing training without decreasing the perceived effectiveness (Lukic, Klein, Brügger, Keller, Fleisch & Kowatsch, 2021).

Pham et al. (2016) conducted a randomized controlled trial to evaluate the feasibility of the breathing retraining game ‘Flowly’ among participants with mental health disorders including depression, generalized anxiety disorder, panic disorder, obsessive-compulsive disorder, posttraumatic stress disorder, and social anxiety disorder. The application provided breathing retraining exercises and diaphragmatic breathing through various minigames with different themes and user engagements interfaces. In the intervention condition (n = 31), participants received access to ‘Flowly’ for 4 weeks. In the control condition (n = 32), participants were placed on a waitlist for 4 weeks before being offered free access to ‘Flowly’. Participants perceived ‘Flowly’ as a fun, engaging and useful intervention. Most importantly, the analysis revealed a reduction in anxiety, panic, and self-report hyperventilation scores and greater quality of life.

Choi et al. (2021) introduced aSpire—a mobile tactile feedback device that guides users to control their breathing rate. aSpire can be easily clipped to a strap/belt and used to personalize tactile stimulation patterns, intensity, and frequency via its array of air pouch actuators that inflate/deflate individually. To evaluate the effectiveness of aSpire’s different tactile stimulation patterns in guiding the breathing rate of people on the move, they conducted a user study with car passengers in a real-world commuting setting. A total of 15 participants ranging from 20 to 38 years old took part in the study. The results showed that engaging with the aSpire does not evoke extra mental stress, and helps the participants reduce their average breathing rate while keeping their perceived pleasantness and energy level high.

4. Discussion & Conclusions

In the current review paper, we examined the physiological as well as neuropsychological effects of breathing training along with the role of mobile applications in the aforementioned objective.

The results of this review showed that individuals who voluntarily apply **breathing training techniques**:

- Strengthen the lungs, improve their *vital capacity*, increase the *elastic properties* of the lung and chest while enhancing *respiratory endurance* (Jansang et al., 2016; Budhi et al., 2019; Hakked et al., 2017).
- Normalize *dioxide carbon levels*, improve *respiratory homeostasis (CO₂-O₂ balance)* and prevent hypoxic and hypercapnic responses (Szulczewski, 2019; Spicuza et al., 2000; Sankar et al., 2018).
- Restore *blood's acid-base imbalances* and voluntarily modify *blood's pH* (Kox et al., 2014; El-Nahas et al., 2019).
- Decrease *inflammatory markers*, decrease *anti-inflammatory mediators*, increase *natural killers cells*, decrease *free radicals* and thus reduces *oxidative stress* while significantly improving *antioxidant defense status* (Bhattacharya et al., 2002; Martareli et al., 2011, Sharma et al., 2003, 2008; Buijze et al., 2019; Kox et al., 2014; Kochupillai et al., 2005).
- Increase *neurotrophic factors (BDNF) and growth factors*, such as the VEGF (Helan et al., 2014; Vermehren et al., 2012; Malshe, 2011).
- Modify hormones like *hormones of stress* (cortisol, ACTH, norepinephrine), *anti-stress hormones* (melatonin, GABA, prolactin), and hunger hormones (Martareli et al., 2011; Ma et al., 2017; Kox et al., 2014).
- Regulate *body temperature*, increasing temperature via heat-generating breathing techniques, or reducing temperature via cooling breathing techniques (Kozhevnikof et al., 2013; Telles et al., 2020).
- Improve voluntary control over *the Autonomic Nervous system* either in favor of the *Sympathetic* or *Parasympathetic nervous System* (Pal et al., 2004; Komori et al., 2018; Mourya et al., 2009; Telles et al, 1994; Laborde et al., 2021).
- Modulate *brain oscillations* and promotes *brain waves (hyper) synchronization* (Bing-Canar et al., 2016; Malhorta et al., 2021; Braboszcz et al., 2017; Viallate et al., 2009).
- *Attention, Consciousness, and Breathing* are characterized by *bi-directionality*. Attention to breathing boosts self-regulation and respiratory homeostasis, while steadiness of breath improves focus, attentional stability, control, and conscious experience (Melnychun et al., 2018; Zelano et al., 2016).
- Produce *altered states of consciousness* via modification of blood gasses as well as acid-base balance including *euphoria, transcendence, mental quiescence* (Miller et al., 2015; Chatter et al., 2021; Viallate et al., 2009).
- Facilitate *relaxation, resilience, and life satisfaction* (Divya et al., 2021; Chandla et al., 2013).
- Promote *longevity, improve survival rate* and activate endogenous *regenerative properties* (Wu et al., 2017; Nekada et al., 2017; Malshe, 2011).

Mobile breathing applications was found to:

- Act as *teaching tools* for breathing training by utilizing *real-time biofeedback* (Bruggeman et al., 2018).
- Combine effective *visualization of the instruction* with *biofeedback* to help people who are unfamiliar with breathing techniques (Fraust-Christmannet et al., 2019).
- Foster *relaxation* along with *intrinsic motivation, engagement, and enjoyment* via the use of richer graphics, more *interactive*, and *gameful elements* with increased *experiential value*. Apps provide various breathing *minigames* with different *themes* and user engagements *interfaces* (Lukic et al., 2021; Pham et al., 2016).

- Cultivate users' ability to *identify* their *internal physiological processes* (Walsh et al., 2019).
- Enable users to *learn how to change physiological activity* to improve health as well as cognitive performance (Chelidoni et al., 2020).
- Elevate *heart rate variability*, an indicator of *parasympathetic dominance* and *resilience* (Chelidoni et al., 2020).
- *Accelerate physiological recovery* after a brief psychological stressor (Plans et al., 2019).
- Help users to *overcome inappropriate breathing patterns* resulting in a *reduction of intense anxiety and panic* (Chittaro et al., 2014).
- Breathing apps running on smartwatches were found to improve *focus* and *reduce anxiety* (Dibia, 2016).

Breathing training techniques and applications assure health, quality of life and well-being without cost. Training in breathing control techniques has long-term physiological & neuropsychological benefits. Training in these techniques not only surpasses the placebo effect but also reduces the symptoms of chronic disorders as well as the concomitant disturbances. In many cases, breathing education and training help patients to drastically reduce the intake of medical treatment, which provokes various adverse effects. Patients become independent, able to learn and take control of their situation. This is an additional reason why breathing training was found to improve patients' self-satisfaction and self-esteem (Cowie, Conley, Underwood & Reader, 2008; El-Nahas et al., 2019).

Mobile applications provide novel opportunities to facilitate breathing training. They are cost-effective, easy to operate and adaptable. The use of different themes, richer graphics, more interactive and gameful elements have a positive role in motivating breathing regulation behaviors. Most importantly, they can support users to develop the ability to systematically monitor and control their breathing behavior.

Thus, this paper concludes that breathing not only constitutes a tool for the regulation and upgrade of various physiological and neuropsychological processes. Most importantly, this 'tool' can be used by humans consciously and voluntarily as a means to take control of their physical, mental, emotional and spiritual wellness. It is noteworthy that conscious modifications of breathing patterns can lead to altered states of consciousness. It is not a coincidence that therapists that use hypno-training recognize breathing patterns as an important factor to induce altered states of consciousness (Drigas & Mitsea, 2022). According to Drigas & Mitsea (2020), expansion of consciousness is to some degree under our control and requires training with the aim to develop the highest form of intelligence, known as Spiritual Intelligence.

The research showed that breathing constitutes a complex process. According to Drigas and Mitsea (2020, 2021) abilities as those required in breath-control training strategies are considered metacognitive. According to their definition: 'Metacognition refers to a set of consciousness-raising skills and strategies through which individuals direct their actions towards optimal performance. Metacognition involves individuals' ability to observe, regulate and adapt their internal cognitive processes, recognize the difference between functional and dysfunctional states of mind and consciously choose those states that awaken the full range of their abilities and identity' (Drigas & Mitsea, 2020, 2021, Mitsea & Drigas, 2019).

Metacognition in breathing refers to the (1) knowledge people have about the power of the breath, (2) awareness of their breathing status in real circumstances along with the

parameters that affect their breathing, (3) attention and real-time observation on breath, (4) conscious regulation of the breathing parameters (i. speed, depth, the rhythm of respiration, frequency, inspiration/expiration ratio, area of movement), (5) adaptations required to reach the desired breathing pattern, (6) recognition of those latent conditions (internal or external) that tend to provoke alterations in breathing, (7) decisions made to let unhelpful operations go away, (8) remembering to consciously breathe.

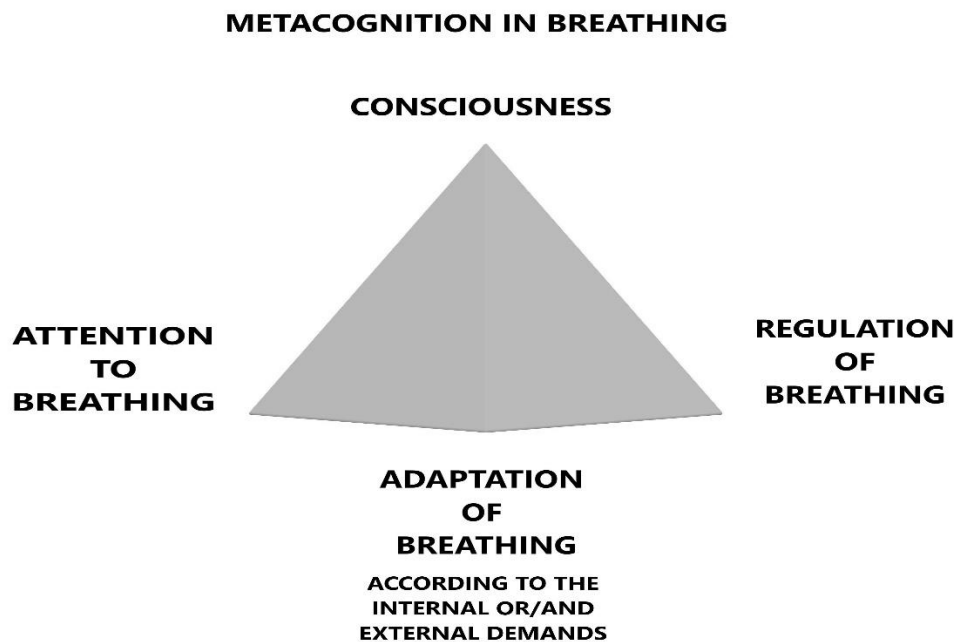


Figure 1. Metacognition in Breathing: Metacognition, Breathing & Homeostasis are characterized by bi-directionality. However, Metacognition provides humans with those meta-abilities (i.e. observation, regulation & adaptation) needed to take control of their breathing patterns according to the internal/external demands and goals.

References

- [1] Bahenský, Petr & Marko, David & Grosicki, Greg & Malátová, Renata. (2020). Warm-up breathing exercises accelerate VO₂ kinetics and reduce subjective strain during incremental cycling exercise in adolescents. *Journal of Physical Education and Sport*. 20. 3361-3367. 10.7752/jpes.2020.06455.
- [2] Barker, N., Thevasagayam, R., Ugonna, K., & Kirkby, J. (2020). Pediatric dysfunctional breathing: proposed components, mechanisms, diagnosis, and management. *Frontiers in Pediatrics*, 8, 379.
- [3] Barroso, A. T., Martín, E. M., Romero, L. M. R., & Ruiz, F. O. (2018). Factors affecting lung function: a review of the literature. *Archivos de Bronconeumología (English Edition)*, 54(6), 327-332.
- [4] Becke, A., Müller, P., Dordevic, M., Lessmann, V., Brigadski, T., & Müller, N. G. (2018). Daily intermittent normobaric hypoxia over 2 weeks reduces BDNF plasma

- levels in young adults—a randomized controlled feasibility study. *Frontiers in physiology*, 9, 1337.
- [5] Bhattacharya, S., Pandey, U. S., & Verma, N. S. (2002). Improvement in oxidative status with yogic breathing in young healthy males. *Indian journal of physiology and pharmacology*, 46(3), 349–354.
- [6] Bickler, P. E., Feiner, J. R., Lipnick, M. S., Batchelder, P., MacLeod, D. B., & Severinghaus, J. W. (2017). Effects of acute, profound hypoxia on healthy humans: implications for safety of tests evaluating pulse oximetry or tissue oximetry performance. *Anesthesia & Analgesia*, 124(1), 146-153.
- [7] Bing-Canar, H., Pizzuto, J., & Compton, R. J. (2016). Mindfulness-of-breathing exercise modulates EEG alpha activity during cognitive performance. *Psychophysiology*, 53(9), 1366-1376.
- [8] Braboszcz, C., Cahn, B. R., Levy, J., Fernandez, M., & Delorme, A. (2017). Increased gamma brainwave amplitude compared to control in three different meditation traditions. *PloS one*, 12(1), e0170647.
- [9] Brinkman, J. E., Toro, F., & Sharma, S. (2020). Physiology, respiratory drive. *StatPearls [Internet]*.
- [10] Bruggeman, K. J., & Wurster, S. W. (2018). The Hiatus system: virtual healing spaces: low dose mindfulness based stress reduction virtual reality application. In *ACM SIGGRAPH 2018 Appy Hour* (pp. 1-2).
- [11] Budhi, R. B., Payghan, S., & Deepeshwar, S. (2019). Changes in lung function measures following Bhastrika Pranayama (bellows breath) and running in healthy individuals. *International journal of yoga*, 12(3), 233.
- [12] Buijze, G. A., De Jong, H. M. Y., Kox, M., van de Sande, M. G., Van Schaardenburg, D., Van Vugt, R. M., ... & Baeten, D. L. P. (2019). An add-on training program involving breathing exercises, cold exposure, and meditation attenuates inflammation and disease activity in axial spondyloarthritis—A proof of concept trial. *PloS one*, 14(12), e0225749.
- [13] Chandla, S. S., Sood, S., Dogra, R., Das, S., Shukla, S. K., & Gupta, S. (2013). Effect of short-term practice of pranayamic breathing exercises on cognition, anxiety, general well being and heart rate variability. *Journal of the Indian Medical Association*, 111(10), 662-665.
- [14] Chater, A. M. (2021). Does intentional asphyxiation by strangulation have addictive properties?. *Addiction*, 116(4), 718-724.
- [15] Chelidoni, O., Plans, D., Ponzo, S., Morelli, D., & Cropley, M. (2020). Exploring the Effects of a Brief Biofeedback Breathing Session Delivered Through the BioBase App in Facilitating Employee Stress Recovery: Randomized Experimental Study. *JMIR mHealth and uHealth*, 8(10), e19412.
- [16] Chittaro, L., & Sioni, R. (2014). Evaluating mobile apps for breathing training: The effectiveness of visualization. *Computers in Human Behavior*, 40, 56-63.
- [17] Choi, K. Y., Lee, J., ElHaouij, N., Picard, R., & Ishii, H. (2021). aSpire: Clippable, Mobile Pneumatic-Haptic Device for Breathing Rate Regulation via Personalizable Tactile Feedback. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1-8).
- [18] CliftonSmith, T., & Rowley, J. (2011). Breathing pattern disorders and physiotherapy: inspiration for our profession. *Physical therapy reviews*, 16(1), 75-86.
- [19] Colebatch, H. J., Greaves, I. A., & Ng, C. K. (1979). Exponential analysis of elastic

- recoil and aging in healthy males and females. *Journal of Applied Physiology*, 47(4), 683-691.
- [20] Cowie, R. L., Conley, D. P., Underwood, M. F., & Reader, P. G. (2008). A randomised controlled trial of the Buteyko technique as an adjunct to conventional management of asthma. *Respiratory medicine*, 102(5), 726-732.
- [21] Davies, S., & Misra, U. (2014). Respiration: ventilation. *Anaesthesia & Intensive Care Medicine*, 15(11), 544-546.
- [22] Dhaniwala, N. K. S., Dasari, V., & Dhaniwala, M. N. (2020). Pranayama and Breathing Exercises-Types and Its Role in Disease Prevention & Rehabilitation. *Journal of Evolution of Medical and Dental Sciences*, 9(44), 3325-3331.
- [23] Dibia, V. (2016). Foqus: A smartwatch application for individuals with adhd and mental health challenges. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 311-312).
- [24] Divya, K., Bharathi, S., Somya, R., & Darshan, M. H. (2021). Impact of a yogic breathing technique on the well-being of healthcare professionals during the COVID-19 pandemic. *Global Advances in Health and Medicine*, 10, 2164956120982956.
- [25] Drigas, A., Mitsea, E., & Skianis, C. (2022). Neuro-Linguistic Programming, Positive Psychology & VR in Special Education. *Scientific Electronic Archives*, 15(1).
- [26] Drigas, A., Mitsea, E., & Skianis, C. (2022). Clinical Hypnosis & VR, Subconscious Restructuring- Brain Rewiring & the Entanglement with the 8 Pillars of Metacognition X 8 Layers of Consciousness X 8 Intelligences. *International Journal of Online and Biomedical Engineering (iJOE)*, 18(01), pp. 78–95. <https://doi.org/10.3991/ijoe.v18i01.26859>
- [27] Drigas, A., & Mitsea, E. (2021). 8 Pillars X 8 Layers Model of Metacognition: Educational Strategies, Exercises & Trainings. *International Journal of Online & Biomedical Engineering*, 17(8).
- [28] Drigas, A., & Mitsea, E. (2021). Metacognition, Stress-Relaxation Balance & Related Hormones. *Int. J. Recent Contributions Eng. Sci. IT*, 9(1), 4-16.
- [29] Drigas, A., & Mitsea, E. (2020). A Metacognition Based 8 Pillars Mindfulness Model and Training Strategies. *Int. J. Recent Contributions Eng. Sci. IT*, 8(4), 4-17.
- [30] Drigas, A., & Mitsea, E. (2020). The 8 pillars of Metacognition. *International Journal of Emerging Technologies in Learning (iJET)*, 15(21), 162-178.
- [31] Drigas, A., & Mitsea, E. (2020). The Triangle of Spiritual Intelligence, Metacognition and Consciousness. *International Journal of Recent Contributions from Engineering, Science & IT (iJES)*, 8(1), pp. 4–23. <https://doi.org/10.3991/ijes.v8i1.12503>
- [32] El-Nahas, Nesreen & El-Deen, Heba & Ahmed, Khaled & Ghaly, Lamis. (2019). Effect of buteyko breathing on modulation of acid base balance among asthmatic patients. *Bioscience Research*. 16. 281-286.
- [33] Faust-Christmann, C. A., Taetz, B., Zolynski, G., Zimmermann, T., & Bleser, G. (2019). A biofeedback app to instruct abdominal breathing (breathing-mentor): pilot experiment. *JMIR mHealth and uHealth*, 7(9), e13703.
- [34] Fitting, J. W. (2015). From breathing to respiration. *Respiration*, 89(1), 82-87.
- [35] Galano, A., Tan, D. X., & Reiter, R. J. (2018). Melatonin: a versatile protector against oxidative DNA damage. *Molecules*, 23(3), 530.
- [36] Hakked, C. S., Balakrishnan, R., & Krishnamurthy, M. N. (2017). Yogic breathing practices improve lung functions of competitive young swimmers. *Journal of Ayurveda and integrative medicine*, 8(2), 99-104.

- [37] Hamasaki, H. (2020). Effects of Diaphragmatic Breathing on Health: A Narrative Review. *Medicines*, 7(10), 65.
- [38] Helan, M., Aravamudan, B., Hartman, W. R., Thompson, M. A., Johnson, B. D., Pabelick, C. M., & Prakash, Y. S. (2014). BDNF secretion by human pulmonary artery endothelial cells in response to hypoxia. *Journal of molecular and cellular cardiology*, 68, 89-97.
- [39] Jansang, S., Mickleborough, T., & Suksom, D. (2016). Effects of Pursed-Lip Breathing Exercise Using Windmill Toy on Lung Function and Respiratory Muscle Strength in the Elderly. *Journal of the Medical Association of Thailand= Chotmai-het Thangphaet*, 99(9), 1046-1051.
- [40] Jelinčić, V., Van Diest, I., Torta, D. M., & von Leupoldt, A. (2021). The breathing brain: The potential of neural oscillations for the understanding of respiratory perception in health and disease. *Psychophysiology*, e13844.
- [41] Jerath, R., Crawford, M. W., Barnes, V. A., & Harden, K. (2015). Self-regulation of breathing as a primary treatment for anxiety. *Applied psychophysiology and biofeedback*, 40(2), 107-115.
- [42] Kochupillai, V., Kumar, P., Singh, D., Aggarwal, D., Bhardwaj, N., Bhutani, M., & Das, S. N. (2005). Effect of rhythmic breathing (Sudarshan Kriya and Pranayam) on immune functions and tobacco addiction. *Annals of the New York Academy of Sciences*, 1056(1), 242-252.
- [43] Komori T. (2018). Extreme prolongation of expiration breathing: Effects on electroencephalogram and autonomic nervous function. *Mental illness*, 10(2), 7881. <https://doi.org/10.4081/mi.2018.7881>
- [44] Komori T. (2018). The relaxation effect of prolonged expiratory breathing. *Mental illness*, 10(1), 7669. <https://doi.org/10.4081/mi.2018.7669>
- [45] Kox, M., van Eijk, L. T., Zwaag, J., van den Wildenberg, J., Sweep, F. C., van der Hoeven, J. G., & Pickkers, P. (2014). Voluntary activation of the sympathetic nervous system and attenuation of the innate immune response in humans. *Proceedings of the National Academy of Sciences*, 111(20), 7379-7384.
- [46] Kozhevnikov, M., Elliott, J., Shephard, J., & Gramann, K. (2013). Neurocognitive and somatic components of temperature increases during g-Tummo meditation: legend and reality. *PloS one*, 8(3), e58244.
- [47] Kuppusamy, M., Kamaldeen, D., Pitani, R., Amaldas, J., & Shanmugam, P. (2018). Effects of Bhramari Pranayama on health—a systematic review. *Journal of traditional and complementary medicine*, 8(1), 11-16.
- [48] Laborde, S., Iskra, M., Zammit, N., Borges, U., You, M., Sevoz-Couche, C., & Dosseville, F. (2021). Slow-Paced Breathing: Influence of Inhalation/Exhalation Ratio and of Respiratory Pauses on Cardiac Vagal Activity. *Sustainability*, 13(14), 7775.
- [49] Li, Y., Wang, M. S., Otecko, N. O., Wang, W., Shi, P., Wu, D. D., & Zhang, Y. P. (2017). Hypoxia potentially promotes Tibetan longevity. *Cell research*, 27(2), 302-305.
- [50] Lukic, Y. X., Reguera, A. H., Cotti, A., Fleisch, E., & Kowatsch, T. (2021). Physiological Responses and User Feedback on a Gameful Breathing Training App: Within-Subject Experiment. *JMIR serious games*, 9(1), e22802.
- [51] Lukic, Y., Klein, S., Brügger, V., Keller, O., Fleisch, E., & Kowatsch, T. (2021). The Impact of a Gameful Breathing Training Visualization on Intrinsic Experiential Value, Perceived Effectiveness, and Engagement Intentions: Between-subject Online Experiment. *Journal of Medical Internet Research (JMIR) Preprints*, (17/05/2021:

- 22803).
- [52] Ma, X., Yue, Z. Q., Gong, Z. Q., Zhang, H., Duan, N. Y., Shi, Y. T., & Li, Y. F. (2017). The effect of diaphragmatic breathing on attention, negative affect and stress in healthy adults. *Frontiers in psychology*, 8, 874.
- [53] Malhotra, V., Hulke, S. M., Bharshankar, R., Chouhan, S., Ravi, N., & Patrick, K. P. (2021). Effect of Slow and Deep Breathing on Brain Waves in Regular Yoga Practitioners. *Mymensingh medical journal: MMJ*, 30(4), 1163-1167.
- [54] Malshe, P. C. (2011). Nisshesha rechaka pranayama offers benefits through brief intermittent hypoxia. *Ayu*, 32(4), 451.
- [55] Martarelli, D., Cocchioni, M., Scuri, S., & Pompei, P. (2011). Diaphragmatic breathing reduces exercise-induced oxidative stress. *Evidence-Based Complementary and Alternative Medicine*, 2011.
- [56] Melnychuk, M. C., Dockree, P. M., O'Connell, R. G., Murphy, P. R., Balsters, J. H., & Robertson, I. H. (2018). Coupling of respiration and attention via the locus coeruleus: Effects of meditation and pranayama. *Psychophysiology*, 55(9), e13091.
- [57] Miller, T., & Nielsen, L. (2015). Measure of significance of holotropic breathwork in the development of self-awareness. *The Journal of Alternative and Complementary Medicine*, 21(12), 796-803.
- [58] Mitsea, E., & Drigas, A. (2019). A Journey into the Metacognitive Learning Strategies. *International Journal of Online & Biomedical Engineering*, 15(14).
- [59] Morris, M., & Guilak, F. (2009). Mobile heart health: project highlight. *IEEE Pervasive Computing*, 8(2), 57-61.
- [60] Mourya, M., Mahajan, A. S., Singh, N. P., & Jain, A. K. (2009). Effect of slow-and fast-breathing exercises on autonomic functions in patients with essential hypertension. *The journal of alternative and complementary medicine*, 15(7), 711-717.
- [61] Nakada, Y., Canseco, D. C., Thet, S., Abdisalaam, S., Asaithamby, A., Santos, C. X., ... & Sadek, H. A. (2017). Hypoxia induces heart regeneration in adult mice. *Nature*, 541(7636), 222-227.
- [62] Navarrete-Opazo, A., & Mitchell, G. S. (2014). Therapeutic potential of intermittent hypoxia: a matter of dose. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 307(10), R1181-R1197.
- [63] Pal, G. K., Agarwal, A., Karthik, S., Pal, P., & Nanda, N. (2014). Slow yogic breathing through right and left nostril influences sympathovagal balance, heart rate variability, and cardiovascular risks in young adults. *North American journal of medical sciences*, 6(3), 145.
- [64] Pal, G. K., Velkumary, S., & Madanmohan, A. (2004). Effect of short-term practice of breathing exercises on autonomic functions in normal human volunteers. *Indian Journal of Medical Research*, 120, 115-121.
- [65] Pham, Q., Khatib, Y., Stansfeld, S., Fox, S., & Green, T. (2016). Feasibility and efficacy of an mHealth game for managing anxiety: "flowy" randomized controlled pilot trial and design evaluation. *Games for health journal*, 5(1), 50-67.
- [66] Plans, D., Morelli, D., Sütterlin, S., Ollis, L., Derbyshire, G., & Cropley, M. (2019). Use of a biofeedback breathing app to augment poststress physiological recovery: randomized pilot study. *JMIR formative research*, 3(1), e12227.
- [67] Sankar, J., & Das, R. R. (2018). Asthma— A disease of how we breathe: role of breathing exercises and pranayam. *The Indian Journal of Pediatrics*, 85(10), 905-910.
- [68] Sharma, H., Datta, P., Singh, A., Sen, S., Bhardwaj, N. K., Kochupillai, V., & Singh,

- N. (2008). Gene expression profiling in practitioners of Sudarshan Kriya. *Journal of psychosomatic research*, 64(2), 213-218.
- [69] Sharma, H., Sen, S., Singh, A., Bhardwaj, N. K., Kochupillai, V., & Singh, N. (2003). Sudarshan Kriya practitioners exhibit better antioxidant status and lower blood lactate levels. *Biological psychology*, 63(3), 281-291.
- [70] Shukla, V., Singh, S. N., Vats, P., Singh, V. K., Singh, S. B., & Banerjee, P. K. (2005). Ghrelin and leptin levels of sojourners and acclimatized lowlanders at high altitude. *Nutritional neuroscience*, 8(3), 161-165.
- [71] Spicuzza, L., Gabutti, A., Porta, C., Montano, N., & Bernardi, L. (2000). Yoga and chemoreflex response to hypoxia and hypercapnia. *The Lancet*, 356(9240), 1495-1496.
- [72] Szulczewski, M. T. (2019). Training of paced breathing at 0.1 Hz improves CO2 homeostasis and relaxation during a paced breathing task. *Plos one*, 14(6), e0218550.
- [73] Swenson, E. R. (2016). Hypoxia and its acid–base consequences: from mountains to malignancy. *Hypoxia*, 301-323.
- [74] Telles, S., Gandharva, K., Gupta, R. K., Sharma, S. K., & Balkrishna, A. (2020). Body temperature in practitioners of a yoga breathing technique considered to be heat generating. *International Journal of Yoga*, 13(2), 168.
- [75] Telles, S., Gandharva, K., Sharma, S. K., Gupta, R. K., & Balkrishna, A. (2020). Body Temperature and Energy Expenditure During and After Yoga Breathing Practices Traditionally Described as Cooling. *Medical science monitor basic research*, 26, e920107-1.
- [76] Telles, S., Nagarathna, R., & Nagendra, H. R. (1994). Breathing through a particular nostril can alter metabolism and autonomic activities. *Indian Journal of Physiology and Pharmacology*, 38, 133-133.
- [77] Thanalakshmi, J., Ravindran, R., Sembulingam, K., & Sembulingam, P. (2014). Impact of sheetali and sheetkari pranayama on the topographic mapping of the brain waves. *IOSR Journal Of Pharmacy*, 4(10), 51-57
- [78] Theodorou, P., & Drigas, A. S. (2017). ICTs and Music in Generic Learning Disabilities. *International Journal of Emerging Technologies in Learning*, 12(4).
- [79] Vedamurthachar, A., Janakiramaiah, N., Hegde, J. M., Shetty, T. K., Subbakrishna, D. K., Sureshbabu, S. V., & Gangadhar, B. N. (2006). Antidepressant efficacy and hormonal effects of Sudarshana Kriya Yoga (SKY) in alcohol dependent individuals. *Journal of affective disorders*, 94(1-3), 249-253.
- [80] Vermehren-Schmaedick, A., Jenkins, V. K., Knopp, S. J., Balkowiec, A., & Bissonnette, J. M. (2012). Acute intermittent hypoxia-induced expression of brain-derived neurotrophic factor is disrupted in the brainstem of methyl-CpG-binding protein 2 null mice. *Neuroscience*, 206, 1-6.
- [81] Vialatte, F. B., Bakardjian, H., Prasad, R., & Cichocki, A. (2009). EEG paroxysmal gamma waves during Bhramari Pranayama: a yoga breathing technique. *Consciousness and cognition*, 18(4), 977-988.
- [82] Walsh, K. M., Saab, B. J., & Farb, N. A. (2019). Effects of a mindfulness meditation app on subjective well-being: Active randomized controlled trial and experience sampling study. *JMIR mental health*, 6(1), e10844.
- [83] Wu, W. J., Wang, S. H., Ling, W., Geng, L. J., Zhang, X. X., Yu, L., ... & Zhao, H. L. (2017). Morning breathing exercises prolong lifespan by improving hyperventilation in people living with respiratory cancer. *Medicine*, 96(2).
- [84] Zaccaro, A., Piarulli, A., Laurino, M., Garbella, E., Menicucci, D., Neri, B., &

- Gemignani, A. (2018). How breath-control can change your life: a systematic review on psycho-physiological correlates of slow breathing. *Frontiers in human neuroscience, 12*, 353.
- [85] Zelano, C., Jiang, H., Zhou, G., Arora, N., Schuele, S., Rosenow, J., & Gottfried, J. A. (2016). Nasal respiration entrains human limbic oscillations and modulates cognitive function. *Journal of Neuroscience, 36*(49), 12448-12467.
- [86] Zhu, X. H., Yan, H. C., Zhang, J., Qu, H. D., Qiu, X. S., Chen, L., & Gao, T. M. (2010). Intermittent hypoxia promotes hippocampal neurogenesis and produces antidepressant-like effects in adult rats. *Journal of Neuroscience, 30*(38), 12653-12663.