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Breathing, Attention & Consciousness in Sync: The role of Breathing Training, Metacognition & Virtual Reality

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Abstract. The purpose of the current review study is to shed light on the relationship between respiration and attention. Specifically, we examined whether and how respiration can provoke alterations in attentional states. Secondly, we investigated the benefits of breath-control training techniques in attention. Furthermore, we explored the effectiveness of virtual reality breathing training in improving respiration along with attention. Finally, we discussed the role of metacognition in the conscious synchronization of respiration with attention. It was revealed that every time respiration loses stability, attention fluctuates. Every time respiration is stabilized, attention finds steadiness. The results confirmed that respiration, attention, and as a result consciousness are characterized by bidirectional synchronization since their systems present coupling functions and dynamical interactions. It was also confirmed that breath control practices guarantee instant as well as long-lasting attentional improvements regulating all those mechanisms that strengthen mental alertness firing either the pathways of relaxation or excitation. Conscious-breath training is a practice of mindful metacognition that supports the coupling of attention with respiration. Metacognition in breathing utilizes respiration to improve attention but at the same time attention is used as a tool to consciously control breathing. Finally, breathing control training in virtual reality not only improves attention along with respiration but may finetune internal and external attention. This study concludes that breathing and attention are two 'giant' mechanisms that go hand-in-hand and carry on their 'shoulders' the whole cognition. Training conscious breathing via advanced technologies should be incorporated into the dialogue of education as methods for brain rewiring assuring better inclusion and academic achievement, especially for those with disabilities.

Keywords. respiration, breath-control exercises, attention, metacognition, consciousness, virtual reality, avatars, respiratory biofeedback, serious games

1. Introduction

Respiration, although unconscious and often overlooked comprise a central aspect of our whole being and one of our most vital functions (CliftonSmith & Rowley, 2011). Respiration is 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 maintains tissue oxygenation and promotes balance inside the body, also known as homeostasis (Jelinčić, Van

Diest, Torta & von Leupoldt, 2021). Ventilation mostly occurs automatically in a continuous rhythmic pattern without any conscious effort (Davies & Misra, 2014).

Breathing patterns reflect not only the status of functioning of the respiratory system and the biomechanical system but also the current cognitive state. A disordered breathing pattern can be the first sign of mechanical, physiological, psychological, or cognitive dysfunctions (CliftonSmith & Rowley, 2011).

A growing number of 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).

Attention is considered since the time of Aristotle as the gateway of human cognition, the prerequisite for awareness and consciousness. It is a mechanism that selects information from our sense data and it is characterized by the remarkable property to voluntarily and involuntarily giving priority to some parts of the information that is available at a given moment (Naghavi and Nyberg, 2005). Attention makes people alert for processing external information and provides them with processing capacity (Posner & Stephen J. Boies, 1971). The attentional networks, namely alerting, orienting and executive control regulate a series of control processes and engage crucial brain areas for survival as well as metacognitive abilities (i.e. self-regulation) and consciousness such as the brain stem arousal system, parietal and prefrontal areas (Posner & Petersen, 1990; Petersen & Posner, 2012). As consequence attention is engaged in a large number of mechanisms including the autonomic nervous system, hormones secretion, body temperature (Petersen & Posner, 2012; Drigas & Mitsea, 2021). However, studies have already shown that attention can be trained in favor of consciousness (Petersen & Posner, 2012; Posner, Rothbart & Tang, 2015).

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). Drigas and Mitsea proposed a layered model of metacognition which consists of eight pillars structured on eight distinct layers of consciousness. Each level describes a higher-order control system that operates under the rule of ever-higher meta-attentional processes and abilities. Attention in this model is considered the most vital element since it is omnipresent in every component of metacognition, in every stage of metacognitive development driving people to the higher states of consciousness (Drigas & Mitsea, 2021). However, according to their latest research, attention is also closely associated with mechanisms that function in non-conscious states such as breathing (Drigas, Mitsea & Skianis, 2022; Drigas & Mitsea, 2021; 2022).

Virtual reality (VR) can be defined as an interactive 3D "imaginal system" that replaces a real-world environment with a virtual one. VR is different from other media because it induces the sense of presence, the feeling of being inside the virtual experience (Riva et al., 2016). VR technology has various applications to different areas of research (Lan, Li & Cheung, 2021).

Nowadays, VR is recognized as a powerful tool for rehabilitation and mental health interventions. Many researchers outline the role of VR in attentional disorders intervention (Doulou & Drigas, 2022).

In digital mental health, various studies explore the effectiveness of VR in the context of biofeedback protocols (Rockstroh, Blum & Göritz, 2021). In biofeedback protocols, physiological signals are identified by sensors and fed back to the user in real-time to provide them information about hardly observable bodily functions. Biofeedback protocols aim to develop the user's ability to consciously control their respiration (Giggins, Persson & Caulfield, 2013; Rockstroh et al., 2021). Respiratory biofeedback also aims to increase the awareness toward the breath, help the trainees to better monitor their current breathing style, regulate and adapt it if necessary and offer reinforcement learning by providing pleasing and rewarding feedback stimuli (Gaume et al., 2016).

VR also utilize virtual avatars as training elements alternating users' perspective or creating a feeling of embodiment known as body ownership illusion (Czub and Kowal, 2019). In recent studies, virtual reality breathing-based biofeedback training adds engaging game-like action contexts (Michela et al., 2021). Games offer the possibility to re-create a genuine feeling of threat and immersion, moderate enough for learning to take place while at the same time boosting engagement (Michela et al., 2021; Weerdmeester et al., 2021). It is noteworthy that VR environments promote intuitive learning, help users to effortlessly develop self-regulation skills (Van Rooij et al., 2016).

Many researchers have already made extensive research regarding the mechanisms of respiration and its impact on human health. Furthermore, in recent years, many researchers outline human's ability to consciously control breathing with the aim to improve various physiological and psychophysiological parameters (Hamasaki, 2020; Drigas & Mitsea, 2022). However, there is still a lack of knowledge regarding the relationship between breathing and fundamental cognitive functions such as attention which raises consciousness and assures solving complex tasks. In addition, it is not clear whether pure breathing control training has a positive impact on attention. Furthermore many researchers have already outlined the role of mobile application as intervention tools (Karabatzaki et al., 2018; Stathopoulou et al., 2019; Drigas et al., 2017; Kokkalia et al., 2016, Drigas et al., 2022) to facilitate breathing training. However, little is known about the effectiveness of advanced technologies like virtual reality.

2. Method

The purpose of the current study is to shed light on the relationship between respiration and attention. Specifically, we examine whether and how respiration can provoke alterations in attentional states. Secondly, we investigate the benefits of breath-control training techniques in attention. Finally, we explore the effectiveness of virtual reality breathing training in improving respiration along with attention. Finally, we discuss the possible factors that mediate between attention and respiration as well as the role of metacognition. 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. In this study, we mainly focused on experimental research and randomized clinical trials.

3. Results

3.1 The effects of respiration on attention

According to Chervin et al. (2006) children with severe obstructive apnea are at risk of substantial but reversible attentional disorder combined with hyperactivity. These children often

have a mild-to-moderate breathing disorder, especially during sleep. Gas exchange abnormalities, hypoxia, and the consequent lack of sleep due to microarousals have detrimental effects on attention (Chervin et al., 2006; Sedky, Bennett and Carvalho, 2014).

Driving is a complex task that requires simultaneous processing of visual information, psychomotor function and sustained attention. Karimi et al. (2015) examined whether breathing problems lead to attentional deficits and predict motor vehicle accidents. The results showed that patients with apnea showed more lapses and fewer responses to stimuli. The findings suggest that people with breathing disorders demonstrate deficits in vigilance and they are at risk of motor vehicle accidents.

Mazza et al. (2005) hypothesized that sleep apnoea patients exhibit a broad range of attentional deficits beyond maintenance of wakefulness (i.e. maintaining of wakefulness, sustained and divided attention). Twenty patients and forty controls were tested on three attentional tasks. The analysis of the data revealed that 95% had vigilance and/or other attentional impairments. Not only their ability to remain awake in monotonous situations was impaired but their ability to maintain attention in more stimulating conditions was also affected. These results indicate that breathing disorders alter a large spectrum of attentional processes.

Klein et al. (2010) investigated whether chronic obstructive pulmonary disease (COPD) influences patients' attention and logical thinking. Sixty COPD patients and sixty healthy controls underwent extensive neuropsychological testing for assessing tonic and phasic alertness, orienting and executive attention. The results revealed significant impairments in a wide range of central-nervous networks of attention in the COPD group. Differences were observed in phasic alertness, orienting and reaction time. Regression analysis showed a significant correlation between neuropsychological and physiological parameters. Specifically, it was revealed a correlation between blood carbon dioxide levels and attention. The researchers concluded that blood dioxide levels predict attention deficits and as a consequence logical thinking impairments in COPD patients.

Hu et al. (2015) explored the attentional deficit in 50 patients with sleep apnea-hypopnea and 40 controls. The results showed that patients with the apnea-hypopnea syndrome had significant differences in the executive control network, which plays a crucial role in the regulation of cognition and attentional control. The authors concluded that chronic hypoxia and apnea may be key factors that could diminish attention and executive function.

Hyperventilation, producing hypocapnia or a decreased CO₂ pressure in the blood, is associated with physiological alterations (i.e., increase in the blood pH which enhances the excitability of the neurons) which often cause subjective symptoms of dizziness, concentration problems and derealization. Van Diest et al. (2000) documented actual attentional performance deficits in forty-two participants associated with hyperventilation-produced hypocapnia, up to 3 min after hyperventilating. Nineteen of the 42 participants exhibited apneas after hypocapnic over-breathing. In the hypocapnic condition, the attentional performance was poorer after recovery from hypocapnia. The participants were less concentrated, made more errors and reaction times were slower. The results indicated that hypoxia, as a result of apnea during recovery from hypocapnia, might be a causative factor for the attentional deficit.

Vidotto et al. (2018) examined the attentional mechanisms underlying primary dysfunctional breathing, a condition where people demonstrate erratic patterns of breathing without anatomical abnormalities or physiological alterations. The symptoms vary from 'air hunger' (i.e. breathlessness) to dizziness and palpitations. According to this study, dysfunctional breathing is linked to the emotional state (i.e. stress) which in turn causes breathing instability and as a result decreases the subject's attentional control. These patients appear to encounter

difficulties while trying to reallocate attentional focus. This means that attentional control may be partially compromised. This study indicates that psychological mechanisms have the potential to initiate domino reactions including attention and respiration and it also reveals the close relationship between emotions, attention and respiration.

Zhang et al. (2018) evaluated the attentional performance of indigenous residents who were born and raised in different high altitude areas (2.900, 3.700 & 4200 meters). The researchers applied the event-related potential to identify the underlying neurophysiological basis. The study provided evidence for competition among attentional networks due to high-altitude exposure. Indicatively, it was found that, in the 4.200m residents, executive function was increased but the orienting decreased. Finally, the researchers observed that there exists a threshold of the influence of high altitudes on attentional functions.

Ezra, Dang and Heuser (2011) examined whether mild hyperbaric oxygen therapy could help fifteen subjects who developed attention deficit disorder after exposure to mild toxins. After ten sessions, a significant improvement was observed in attention span and reaction time to stimuli. These results suggest that oxygen detoxifies the brain and thus restores attentional deficits.

Wang et al. (2020) explored the effectiveness of intermitted hypoxia training (breathing hypoxic/low oxygen air) on mild cognitive impairment. This study confirmed that brief, cyclic moderate hypoxemia lowers arterial pressure, enhances cerebrocortical tissue O₂ saturation and cerebral vasodilation during hypoxia challenge and potentially improves performance on tests for attention and short-term memory.

Melnychuk et al. (2018) formalized how 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 via the phrenic nerve. Thus, fluctuations in CO₂ levels provoke alterations to locus coeruleus which fire in sync with respiration and attention.

Melnychuk et al. (2021) investigated the extent to which key cortical and subcortical signatures are synchronized with breath dynamics. To this objective, they examined the tripartite relationship between the respiratory cycle, the EEG theta-beta ratio (a marker for attentional control) and the pupil diameter. The results showed that both theta-beta ratio and pupil diameter are simultaneously synchronized with the breath, suggesting an underlying oscillation of an attentionally relevant electrophysiological index that is phase-locked to the respiratory cycle which could have the potential to bias the attentional system into switching states. This study also highlights the role of locus coeruleus as a coupling mechanism due to its dual functions as both a chemosensitive respiratory nucleus and a pacemaker of the attentional system.

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.

Nobis et al. (2018) confirmed that the amygdala, respiration and attention are closely associated. Electrical stimulation of the amygdala induces apnea, suggesting a functional connection between the amygdala and respiratory control. They also suggested that attentional state is dependent on apnea mediated by amygdala activation. Finally, it was found that people with conscious breathing can prevent apnea preventing epilepsy episodes.

3.2 The benefits of breathing-control techniques on attention

The benefits of relaxatory breathing exercises on attention

Diaphragmatic breathing or deep breathing involves contraction of the diaphragm, expansion of the belly and deepening in inhalation and exhalation, which consequently decreases the respiration frequency and maximizes the amount of blood gases. Ma et al. (2017) investigated the effects of diaphragmatic breathing on attention, affect and cortisol responses to stress. Forty participants were assigned to either a breathing intervention or a control group. After eight weeks, the breathing group showed lower stress hormones, better mood and improved sustained attention.

Kiselev (2021) investigated whether diaphragmatic rhythmic deep breathing could improve the symptoms of inattentiveness in children with attention deficit hyperactivity disorder. The researchers hypothesized that this technique could better supply the brain with oxygen and as a result, it could help children to better control attention. Indeed, it was revealed a significant improvement in control functions responsible for regulating attentional states.

Reports suggest that vigilance increases sympathetic activity and as a result blood pressure. Telles et al. (2017) explored whether alternate nostril yoga breathing could improve the performance in a vigilance test without an increase in blood pressure. Fifteen participants were assessed on (i) alternate nostril breathing, (ii) breath awareness and sitting quietly as a control. The results showed that systolic blood pressure, mean arterial blood pressure, and the time which was taken to complete the digital vigilance test significantly decreased following alternate nostril breathing. These results indicate that breathing training can increase vigilance without sympathetic activation.

Mo et al. (2021) explored the effects of breathing meditation training on sustained attention, mindfulness attention awareness and mental state. Forty participants were divided into two groups, the abdominal breathing group and the control group. After training, the experimental group had lower mental fatigue, improved sustained attention and higher attention awareness than did the control group.

Telles, Singh and Puthige (2013) aimed at comparing the effects of alternate nostril yoga breathing with breath awareness on the P300 task in a total of twenty adults. The P300 amplitude is believed to indicate the resources available to process information about the stimuli. The results demonstrated that alternate nostril yoga breathing positively influenced cognitive processes which are required for sustained attention at different scalp sites (frontal, vertex and parietal), whereas breath awareness brings about changes at the vertex alone. The increased P300 peak amplitude and latency following alternate nostril breathing suggest that this practice relaxes and increases the attentional resources along with better stimulus processing speed and efficiency.

Soni, Joshi and Datta (2015) assessed the effectiveness of controlled deep breathing on psychomotor and higher mental functions. One hundred subjects (18 to 25 years) completed three different tests that evaluated among others attention, concentration, response speed, visual

scanning and short-term memory. The results showed that after six weeks of deep breathing attentional processes significantly improved. The authors assumed that breathing training improved oxygen supply leading to attentional improvements.

Hoffman et al. (2019) whether slow-paced breathing could improve the neurophysiological aspects of error monitoring and executive control in a total of 41 participants. The results showed that slow-paced breathing improved all those factors that boost attention and error monitoring.

Park and Park (2012) evaluated the clinical utility of paced breathing as a concentration practice. Fifty-eight subjects (20 to 30 years) were trained in paced breathing. EEG, HRV, and respiratory data were recorded during spontaneous and paced breathing. In terms of HRV parameters, the high-frequency power increased and the low frequency-to-high frequency ratio decreased during paced breathing. In terms of EEG parameters, low-frequency alpha power, a marker of internal attention, globally increased and theta power, a marker of an advanced meditative state, locally decreased. This indicates that parasympathetic activity and internal attention increased. The results suggest that paced breathing can be utilized as a concentration practice.

Kuppusamy et al. (2020) examined the effectiveness of a calming breathing exercise namely Bhramari pranayama on reaction time. 520 healthy participants were divided into the experimental and the control group. This study revealed that the breathing group showed a significant shortening in both visual and auditory reaction time.

Zaccaro et al. (2018) conducted a review study regarding breath control practices. They found that slow breathing improves all those factors that assure better attention. Specifically, they found that slow breathing decreases heart rate, increases heart rate variability, increases alpha waves while decreasing theta waves. Furthermore, this technique increases activity in the prefrontal cortex and improves functioning in limbic areas which are fundamental to attention.

Sudarshan Kriya Yoga (SKY) is a cyclic breathing exercise that ranges from slow and calming to rapid and stimulating. Bhaskar et al. (2020) observed neuronal oscillations in multifrequency bands and interhemispheric synchronization following SKY training in a total of 44 participants. The results showed that spectral power increased significantly in all frequency bands bilaterally in frontal, central, parietal, temporal, and occipital regions of the brain after SKY. Electrical activity shifted from lower to higher frequency range with a significant rise in the gamma and beta powers. The researchers concluded that a single session of SKY generates global brain rhythm dominantly with high-frequency cerebral activation and initiates appropriate interhemispheric synchronization in brain rhythms. This indicates that SKY leads to better attention, memory, and emotional and autonomic control along with enhanced cognitive functions.

Study	Type of relaxatory breathing exercise	Breathing group	Control group	Age Range	Sessions	Duration	Main findings
Ma et al. (2017)	Diaphragmatic breathing	19	20	30.16	20	15 min.	Improved sustained attention, decreased stress hormone (cortisol), better mood

Telles et al. (2017)	Alternate nostril breathing	15	No control group	22.4	3	15 min.	Better vigilance and reaction time without sympathetic activation
Telles et al. (2013)	Alternate nostril breathing	20 males	No control group	21-38	2	40 min.	Relaxation & better allocation of attentional resources
Soni et al. (2015)	Deep breathing	100 (52 female)	No control group	18-25		6 weeks (once a day for 10 min.)	Better attention, concentration, response speed & visual scanning
Hoffman et al. (2019)	Slow-paced breathing	41 (27 female)	No control group	23.7			Better attention & error monitoring
Park et al. (2012)	Slow-paced breathing	58 (22 female)	No control group	21-30	2	15 min.	Increased internal attention & parasympathetic activity
Kuppusamy et al. (2020)	Bhramari pranayama	260	260			3 days in a week for 6 months	Shorter visual & auditory reaction time
Zaccaro et al. (2018)	Slow breathing	339 (146)	74	21-54			Decreased heart rate, increased heart rate variability, increased alpha waves, better attention
Bhaskar et al. (2020)	Sudarshan Kriya Yoga breathing	40 (23 female)			25.45	3 rhythms of breath (slow, medium, and fast) followed cyclically for 7-8 consecutive rounds (20 min)	Interhemispheric synchronization, increased gamma and beta oscillations, better attention

Table 1: The benefits of relaxatory breathing exercises in attention

The benefits of activatory breathing techniques on attention

Mukh bhastrika is yogic bellows-type breathing which breath, after a deep inspiration, is actively blasted out in 'whooshes' with forced abdominal contractions to expel air (excess carbon dioxide) out of the lungs. Bhastrika constitutes a controlled form of hyperventilation. Shavanani and Udupa (2003) evaluated the effects of Mukh Bhastrika on reaction time in a total of 22 healthy students. The breathing exercise produced a significant decrease in visual as well as auditory reaction time. These results indicate greater arousal, better concentration, and improved ability to ignore distracting stimuli.

Telles et al. (2019) compared the immediate effects of high-frequency yoga breathing, breath awareness, and sitting quietly on attention and anxiety in a total of sixty-one pre-teen

children. Attention was assessed via the six-letter cancellation test, which evaluates the ability to focus, shift attention and recall visual scanning. The results showed that all interventions reduced anxiety, but only high-frequency breathing improved focus and attentional flexibility.

Telles, Singh and Balkrishna (2012) studied the effect of high-frequency yoga breathing (kapalabhati, breath rate 1.0 Hz) and breath awareness on attention (finger dexterity, eye-hand coordination and visual discrimination). One hundred and forty subjects were divided into two groups. The results showed that both exercises can improve attention, with a greater magnitude of change after *kapalabhati*.

Sharma, Kala and Telles (2021) assessed attention and anxiety following four breathing exercises (alternate nostril, bellows breathing, bumblebee breathing and high-frequency breathing). The results showed that sustained attention was better following high-frequency breathing.

Chan et al. (2010) investigated whether Shaolin Dan Tian Breathing techniques (DTB) would induce both relaxed and attentive states in a total of 22 adults. The Shaolin DTB consists of two forms: (i) the passive (by passively observing) and (ii) the active (a warm-relax form of breathing that requires tightening of the anal and abdominal muscles with closed lips and opened eyes during exhalation and closed eyes when inhaling). After one month of training, it was revealed that the passive form of breathing enhanced temporal alpha activity which indicated relaxation and a positive mood. However, the active breathing technique enhanced intra- and inter-hemispheric theta coherence which indicates attention and alertness. These results also demonstrate that this breathing exercise can alter brain activity and connectivity patterns that are responsible for positive mood and attentiveness.

Telles, Joshi and Somvanshi (2012) investigated whether uninostil or alternate nostril breathing could modify the ability to pay attention to a given stimulus. Twenty-nine healthy volunteers (20 to 45 years) were randomly allocated to five sessions: (i) right, (ii) left, (iii) alternate nostril, (iv) breath awareness and (v) no intervention. The P300 event-related potential showed that right nostril breathing facilitates attention and immediate memory.

Bhavanani et al. (2014) aimed to determine the differential effects of breathing techniques on reaction time, heart rate, and blood pressure. Twenty subjects were assessed before and after nine rounds of right uninostil breathing (UNB), left UNB, right initiated alternate nostril breathing (ANB), left initiated ANB, alternate nostril breathing without breath retentions and normal breathing. The results showed improved reaction time for the right uninostil breathing and the right initiated alternate nostril breathing. The study also provided evidence of sympathomimetic effects of right nostril initiated pranayamas with sympatholytic/parasympathomimetic effect following left nostril initiated pranayamas. The researchers also suggested that the main effect of these techniques is determined by the nostril used for inspiration rather than that used for expiration.

Study	Type of activatory breathing exercise	Breathing group	Control group	Age range	Sessions	Duration	Main findings
Bhavanani et al. (2003)	Mukh Brastrika (yogic bellows breathing)	22	No control	13–16	9		Decreased visual & auditory reaction time
Telles et al. (2019)	High-frequency yoga breathing	61 (25 girls)	40	11-12	3	18 min	Improved focus & attentional flexibility

Telles et al. (2012)	high frequency yoga breathing (Kapalabhati)	47 (28 females)	47	20-55		10 min.	Improved attention
Sharma et al. (2021)	High-frequency yoga breathing	38 male	No control group	20-37	6	18 min	Improved sustained attention
Chan et al. (2010)	Shaolin Dan Tian Breathing (active form)	22	20	49.66	4	15min per day for one month	Enhanced intra- & inter-hemispheric theta coherence, better attention & alertness
Telles et al. (2012)	Right nostril breathing	29 males	no control	20-45	5	20 min.	Improved attention
Bhavanani et al. (2014)	Right nostril breathing	20 (13 females)		34.10	6		Improved reaction time

Table 2: The benefits of excitatory breathing exercises in attention

3.3 Virtual Reality Breathing Training

Blum et al. (2019) conducted a randomized controlled experiment with 60 participants to investigate the effectiveness of an immersive virtual environment to administer immersive heart rate variability biofeedback (HRV-BF) based on slow-paced breathing. The results showed that VR-based HRV-BF improved participants' cardiac coherence, enhanced relaxation, reduced distraction and mind wandering, and helped participants to effortlessly focus on the present moment. The authors concluded that the intervention left the user with a higher level of attentional resources than standard implementations. In addition, the virtual environment along with biofeedback and diaphragmatic breathing restored voluntary attentional resources of the observers by directing involuntary attention toward a relaxing and engaging environment.

In a pilot study with 86 children, Weerdmeester et al. (2021) assessed the efficacy of DEEP, a virtual reality biofeedback video game that provided deep breathing training in an immersive and relaxing environment without explicit tasks and goals. On the contrary, it aimed at embodied, intuitive, and exploratory learning. DEEP also provided mild exposure to stressful situations (i.e., dark caves) as a means of enhancing self-regulation skills. Slow and deep breathing allowed players to move in the game. The results of the study showed that DEEP improved internal control and engagement which demonstrates heightened levels of attention. They could also better monitor how successful they were at regulating their breathing. In a similar study, Rooij et al. (2016) found that DEEP helped participants to gain better awareness of the states of breathing, more consciously pay attention to breathing and more effectively regulate attention to achieve the breathing pattern required to move in the virtual game.

Lan, Li and Cheung (2021) proposed a slow-breathing training system based on virtual reality with multimodal feedback to motivate users' engagement in a regular practice of breathing control. In this system, a realistic human model of the trainee (virtual avatar) is provided to mirror their actions. It was revealed that the trainees could more effectively regulate their breathing to achieve a slower and more stable breathing rate. The results of the Stroop task also showed less mind wandering, a better allocation of attentional resources, greater focus along better and more accurate reaction times.

Sra, Xu and Maes (2018) explored the effectiveness of the use of breathing actions as input in virtual reality games. Participants reported a higher sense of presence when using

breathing actions during the virtual gameplay. These results show that breathing control practices improved attention to the present moment. Rockstroh et al. [] developed and evaluated a VR-based respiratory biofeedback game to foster diaphragmatic breathing. The game was designed to run on a mobile, all-in-one VR headset. Notably, an integrated VR hand controller was utilized to detect respiration-induced movements of the diaphragm. The results showed that the brief VR-based breathing training increased their awareness of their breath, which indicates higher conscious attention.

Cook, Huebschmann and Iverson (2021) examined the effectiveness of a virtual reality-based breathing exercise who are slow to recover from a concussion. Fifteen participants completed a 5-min paced deep breathing exercise administered via a VR headset. Nearly all participants were more able to stay mentally focused, while they reported a significant decrease in stress, mental fatigue, and confusion.

Blum, Rockstroh and Göritz (2020) proposed a novel virtual reality-based approach to respiratory biofeedback that utilized the positionally tracked hand controllers to capture and feedback the respiration-induced abdominal movements. Seventy-two participants performed a short breathing exercise in VR with and without respiratory biofeedback. It was found that VR respiratory biofeedback approach resulted in a greater focus on slow diaphragmatic breathing along with heightened breath awareness. The authors outlined that breathing can act as an anchor for focused attention, while VR can support effortless and involuntarily attention.

Yüksel et al. (2020) evaluated the effectiveness of slow breathing in a virtual environment intending to reduce alertness in a total of 29 adolescents. The results showed that VR-based slow breathing enhanced cognitive relaxation, reduced distraction, regulated heart rate variability and reduced vigilance. These results indicate that VR-based breathing training can also modify the non-helpful states of attention.

Pain is an inherently subjective experience that can be modified by our attention. Hu et al. (2021) compared the cortical analgesic processes by imaging the brains of healthy subjects exposed to traditional mindful breathing with virtual reality breathing. The virtual reality breathing protocol involved virtual reality 3D lungs that synchronized with the participants' breathing cycles in real-time, providing them with an immersive visual-auditory exteroception of their breathing. The researchers found that both breathing interventions had analgesic effects. However, the underlying analgesic brain mechanisms were the opposite. The one was associated with neuro mechanisms of interoception and the other with exteroception attention.

Czub and Kowal (2019) examined whether a virtual breathing avatar could help people to improve interoceptive attention as well as the ability to adjust respiratory rate. Participants observed a virtual breathing avatar body from the first-person perspective while their own respiratory was recorded. The avatar was first breathing for 60 seconds following the participant's respiratory rate. Then, it was either slowing down or speeding up. The participants had to synchronize respiration with the visual cues from the avatar. The results showed that the virtual avatar entrained participants' respiratory rates helping them to better sustain attention to the avatar's breath while at the same time they could better be aware of and adapt their breathing patterns.

Michela et al. (2021) developed a virtual reality breathing-based biofeedback training in which police officers performed deep and slow diaphragmatic breathing in an engaging game-like action context. A total of nine participants completed ten sessions for four weeks. The VR game was designed to evaluate response inhibition (shooting accuracy) in high arousal situations. Biofeedback was aimed at maintaining a slow breathing pace. The slower and deeper the breathing, the less constrained peripheral vision became facilitating accurate responses. The

results showed increased voluntary attention to breathing control, physiological awareness, and positive arousal in an active decision-making context. From a training perspective, it was obvious the trainability of deep-breathing as well as attention. VR breathing training helped subjects to gain attentional control by prefrontal regions in high arousal and stressful situations.

4. Discussion & Conclusions

Firstly, we investigated whether respiration can affect attention either positively or negatively. The results showed that respiration not only has an influential impact on attention but it was also confirmed that attention and respiration may be a coupled dynamical system characterized by physiological and functional overlaps (Melnychuk et al., 2018). Respiration has a major impact on several mechanisms by which attention is independent provoking, for instance, acute alterations to the autonomic nervous system or entraining the electrical activity of the brain (Bhaskar, 2020).

Gas exchange abnormalities influence attention. Specifically, the evidence showed that abnormalities in oxygen or carbon dioxide levels directly or indirectly lead to a wide range of attentional deficits, some of them reversible (Klein et al., 2010). Specifically, breathing abnormalities provoke disturbances in the mechanisms of arousal. Subjects have difficulties in maintaining focus, dividing attention with flexibility. They have more lapses and reaction time is often impaired (Van Diest et al., 2000). Deficits are also observed in the executive control network which is responsible for regulating attention and other cognitive abilities (Hu et al., 2015). Thus, it became obvious that fluctuations in breathing result in attentional fluctuations.

However, appropriate alterations in oxygen and carbon dioxide levels can positively affect attention. For instance, oxygen therapy in cases of low oxygen levels or high toxicity improves attentional span and reaction times (Ezra et al., 2011). Interestingly, intermittent hypoxia training may cause improvements in attention because of brief, cyclic moderate hypoxemia that lowers arterial pressure enhances cerebrocortical tissue O₂ saturation and cerebral vasodilation (Wang et al., 2020).

Evidence was found indicating key cortical and subcortical signatures which are synchronized with breath dynamics (Melnychuk et al., 2021). Similar studies found that the rhythm of breathing coordinates electrical activity across a network of brain regions such as the hippocampus and amygdala associated with attention and consciousness (Zelano et al., 2016). These results demonstrate that respiration not only influences brain areas and mechanisms responsible for attention and conscious regulation of cognition but also there exists a synchronized activity as well as overlapping functions between respiration and attentional mechanisms.

The results also revealed that psychological mechanisms have the potential to initiate domino reactions affecting respiration and in turn a series of attentional alterations. These findings indicate the close relationship between emotions, respiration and attention (Vidotto et al., 2018).

Secondly, we examined the effectiveness of breath-control exercises on attention. The results showed that breath-control exercises have a major impact on attention through a series of mechanisms and possible factors. According to the results, attention can be improved either following the pathway of relaxation or the pathway of stimulation without provoking hyperactivity or lethargy.

Relaxatory breathing techniques like diaphragmatic breathing, alternate nostril breathing, slow-paced breathing were found to positively influence a wide range of attentional processes (see table 1). Participants had better performance in attentional tasks. The results

showed improvements in sustained attention, reaction time, attentional control. Subjects had a better awareness of their attention and they could more flexibly monitor and allocate the attentional resources according to the requirements of the tasks. It is noteworthy that improvements in attention were accompanied by lower stress hormones, activation of the parasympathetic nervous system, increased heart rate variability, interhemispheric synchronization. Interestingly, these exercises improved vigilance without sympathetic activation. On the contrary, these techniques oxygenated and brought relaxation allowing participants' attention to function unimpeded.

Breathing-control exercises that are characterized as activatory, such as high-frequency breathing, right nostril breathing, kabalabhati, have also a positive impact on attention. It was found that they improve focus, attentional flexibility, shorten the reaction time and enhance intra- and inter-hemispheric theta coherence, an indicator of attention and alertness. Compared with passive forms of breathing control, it was revealed that when subjects increase the frequency of breathing, attention improves better. These techniques may have a positive impact because they help the subject to remove carbon through a controlled form of hyperventilation. Interestingly, nostril breathing plays a significant role in attention. Results revealed that right nostril breathing has sympathomimetic effects while left nostril breathing sympatholytic effects. It is noteworthy that activatory breathing techniques seem to stimulate attention through the sympathetic nervous system's pathways.

Thirdly we examined the effects of virtual reality breathing training on attention. Immersive virtual reality combined with heart rate variability biofeedback based on slow-paced breathing has positive effects on participants' cardiac coherence, relaxation, distraction and mind wandering, helping participants to effortlessly focus on the present moment. Virtual reality breathing enables subjects to liberate attentional resources by directing involuntary their attention toward relaxing and engaging environments (Blum et al, 2019). Virtual reality biofeedback video games that provide deep breathing training in an immersive and relaxing environment without explicit tasks and goals train players to move in the game with the power of their breathing. This process boosts internal control, better self-monitoring and engagement which in turn indicates heightened levels of attention. Participants also gain better awareness of the states of breathing by consciously paying attention to breathing and more effectively regulating attention to achieve the breathing pattern required to move in the virtual game. Virtual slow-breathing training system as well as the use of virtual avatars motivate users' to learn how to regulate their breathing to achieve a slower and more stable breathing rate (Weerdmeester et al., 2021; Rooij et al. (2016); Li et al., 2021). It is noteworthy that there is evidence that mindful breathing combined with virtual reality can finetune internal with external attention (Hu et al., 2021)

Breathing exercises can help us to recognize the here-and-now reality. Breath control practice is an act of mindful metacognition (figure 1-3) engaging processes like monitoring, regulation and adaptation of breathing aiming to expand conscious attention to the flow of energy and conceive the panoramic "view" of the totality that exists behind every singleton experience with acceptance rather than effortful control (Drigas & Mitsea, 2020; 2022).

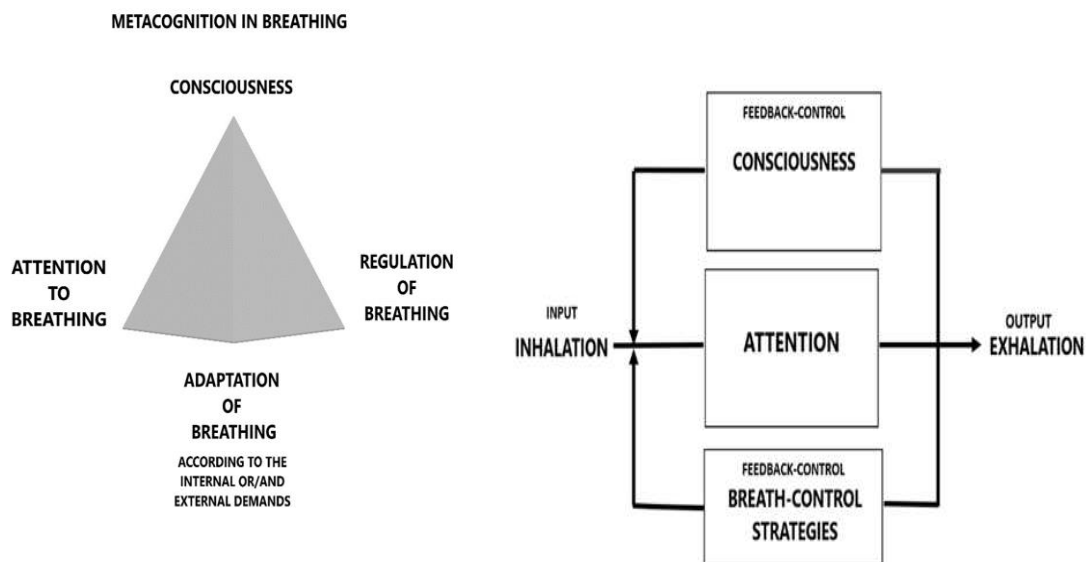
It is necessary to highlight that attention can be used as a tool for conscious breath control. Conscious breath control practices require attention to the breath. For instance, during these exercises, the subjects pay attention to the nostrils, the rising and falling of the chest, or more subtle inner changes. It also requires attentional flexibility to redirect attention internally to the sensations of the breath away from distractions and negative feelings or externally in

cases of biofeedback protocols. Internal and external attention work together to finetune internal and external demands (Boyadzhieva, A., & Kayhan, E. (2021).

Imagine breath like the wind in the sails of attention toward the stream of consciousness. When the wind is calm, attention is clear and the boat sails along with a calm ocean. But when the weather turns and huge waves are tied around the boat while the compass is turning like crazy from one mast to the other, Attention! - it wipes out all the chances. Then, as you are watching over the wheel, you are asking yourself whether it is the ship or the compass that turns. Calm sailing doesn't not only come from a tailwind or calm ocean but mostly from a good navigator. Similarly, attention does not come just from breathing but mostly from the metacognitive navigator who is trained to consciously control breathing to keep attention crystal clear.

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 (figure1-3) (Drigas & Mitsea, 2021;2022).

Metacognitive training in breathing could help people to be more attentive and conscious in favor of a better quality of life, achievement in all areas of life and health in physical, emotional, mental and spiritual levels. Virtual reality constitutes a top technology fom breathing training assuring attentional improvements.



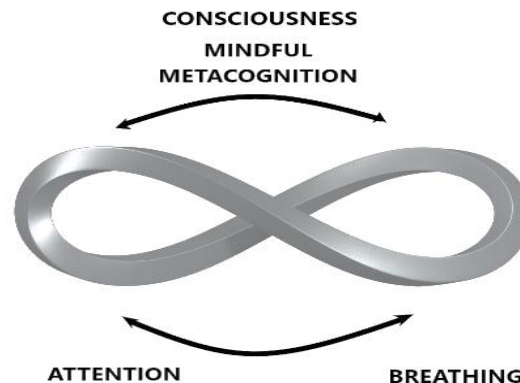


Figure 1-3: Metacognition, Breathing are characterized by bi-directionality. However, Metacognition provides humans with those meta-abilities (i.e. observation, regulation & adaptation) needed to take control of their breathing patterns according to the internal/external demands and goals (left) (Drigas & Mitsea, 2022). The central mechanism of metacognition in breathing depends on the two major control-regulation systems represented via the system's control theory-modeling (right). Attention and respiration are synchronized under the roles of mindful metacognition in an undivided connection (down).

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