

Cardiorespiratory feedback training as a non-pharmacological intervention and its application in stroke patients

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Abstract. The interaction between cardiovascular and respiratory systems is a reciprocal one mediated by mechanical factors, autonomic nervous system, and baroreflex regulation and manifested in the changes in heart rate, blood pressure and ventilation. These changes can be rather easily registered and measured, which opens the opportunity for clinical use (both in diagnostics and therapy).

In the paper we briefly review the potential role and implementation of cardiorespiratory biofeedback in treating patients with neurological diseases, in particular, stroke survivors. The available evidence suggests that this method based on the existing cardiorespiratory coupling mechanisms may prove its efficacy in treating a range of medical conditions including cerebrovascular disorders. The prospects of cardiorespiratory biofeedback application in improving a stroke patient's quality of life (including physical, emotional, and cognitive levels) and clinical status require further investigation. The topicality of determining the long-term effect of novel non-pharmacological interventions as an adjunct to conventional therapies is defined by their limitations and significant pharmacological load.

Keywords: cardiorespiratory coupling, cardiorespiratory feedback, biofeedback, cerebrovascular diseases, neurological diseases, stroke, heart rate variability biofeedback, non-pharmacological intervention.

Interaction between cardiovascular system and respiration

The interaction between cardiovascular and respiratory systems has been extensively studied and described in its physiological and pathological variants. It is a reciprocal interaction which is mediated by mechanical factors (location of the lungs and the heart in the thoracic cavity, changes of the thoracic pleural pressure during respiration), autonomic nervous system (in particular, vagal activity), and baroreflex regulation, and is manifested in the changes in heart rate, blood pressure and ventilation (well-known manifestations are cardiopulmonary reflexes, respiratory sinus arrhythmia, etc.) (Bronicki et al. 2016). These changes can be rather easily registered and measured, which opens an opportunity for clinical use (both in diagnostics and therapy).

In this paper we will discuss the available therapeutic approaches based on (bio)feedback, which involve cardiorespiratory coupling and can be used in the comprehensive treatment of stroke.

Heart rate variability biofeedback

One of the non-pharmacological interventions targeting cardiovascular homeostatic reflexes (Gevirtz 2013) is heart rate variability biofeedback (HRVB), also referred to as respiratory sinus arrhythmia (RSA) biofeedback.

Heart rate variability refers to a measure of the variation among the intervals between consecutive heartbeats over time (Thayer et al. 2012). There is a range of measures used in order to assess HRV, among them standard deviation of all intervals between heartbeats in 24 hours, standard deviation of 5 minute intervals, root mean square of successive differences, and RSA.

RSA corresponds to the increase in heart rate with inhalation and the decrease in heart rate with exhalation and is considered to be a measure of physical and emotional resilience and a reliable physiological marker of autonomic balance, homeostatic regulation, and adaptive stress-response. Low HRV is associated with increased risk of mortality, and HRV has been proposed as a marker for disease (Thayer, Lane 2007).

In HRVB a participant practices a diaphragmatic breathing technique during which their breathing slows down to 6–7 breaths per minute, and RSA is maximized and matched to heart rate patterns. When the pre-assigned training threshold is surmounted, the participant receives feedback which helps to promote and reinforce this physiological pattern.

Operant conditioning model

To some extent we can refer to operant conditioning model (described by B. F. Skinner) when we explore different types of biofeedback (HRVB, EMG biofeedback, EEG biofeedback, galvanic skin response biofeedback, etc.). Operant conditioning as a method of learning establishes the link between a particular type of behaviour and its consequences. Thus, the target physiological pattern (“behaviour”) is positively rewarded, and after sufficient training tends to become reinforced. Essentially, the efficacy of the training significantly depends on a patient’s motivation and compliance, as well as the ability of the therapist to design optimal training protocol, determine and adjust training thresholds and keep biofeedback in line with other interventions which are being applied, i. e. psychotherapy.

HRVB: applications and possible mechanisms

Gevirtz (2013) summarizes scientific sources on the application of HRVB in various disorders and distinguishes the following clusters:

1. Asthma and chronic obstructive pulmonary disease, functional gastrointestinal disorders, cardiovascular disorders, fibromyalgia, hypertension, and chronic muscle pain are considered to be affected by HRVB by means of improved autonomic regulation.

2. Depression, anxiety, and sleep disorders are considered to respond to HRVB via central effects by way of the vagal afferent nerve. Optimal performance is considered to be another intervention target within this proposed mechanism.

3. Lehrer et al. (2010) suggest that HRVB decreases autonomic dysfunction produced by lipopolysaccharide-induced inflammation in patients with inflammatory conditions. Thus, further research is necessary to determine the utility of HRVB in modulating dysfunctional inflammatory responses.

According to Eddie et al. (2015), HRB has potential as an add-on intervention for established substance use disorders treatment protocols as a method to ameliorate autonomic nervous system dysregulation in key processes implicated in the development and maintenance of addictive pathology — affecting dysregulation and craving.

Biofeedback application in stroke: targets and delivery

Here we will focus on stroke as a leading cause of disability among neurological diseases. Effective non-pharmacological rehabilitation methods are

constantly being sought to complement conventional therapies, among them non-invasive brain stimulation, brain-machine interfaces, biofeedback, various types of psychotherapy, etc.

The most common biofeedback therapeutic targets in stroke patients are gait biomechanics and upper limb and lower limb sensorimotor deficits. Recent research also investigates the effects of neurofeedback on brain plasticity and cognitive processes (Kober et al. 2017).

Biofeedback is traditionally delivered via visual, acoustic or haptic modalities. It means that the information on physiological changes (muscle tension, heart rate, breathing, electrical activity of the brain, skin conductance, temperature, etc.) is measured by electrical sensors and fed back to the patient via stimuli of different modalities (pictures/video, sound, or multimodal biofeedback). As well as a training tool, biofeedback equipment can serve diagnostic purposes: it can be used to register and analyze the above-mentioned data.

Virtual reality (VR) environment is a novel biofeedback delivery channel. It is an environment generated by technical means replicating reality as closely as possible, which is transmitted to a person via visual, acoustic or haptic modalities. VR simulates both exposure and response to exposure. In order to create a convincing image of reality, a computer synthesis of the characteristics of and reactions to VR is performed in real time, involving various technologies.

VR, which began its development in the form of computer games, quickly proved itself as an effective method of neurorehabilitation. A major experience in using VR has been accumulated in the field of motor function recovery after stroke (Cirstea, Levin 2000; Bourbonnais, Vanden Noven 1989; Bourbonnais et al 1992).

One possible feature determining the efficacy of VR in motor function recovery after stroke is the stimulation of motor imagery by means of visual feedback. Research literature distinguishes two components of motor imagery: the visual and the kinaesthetic one. In the VR method, positive visual feedback is added to the imagery. To date, therapeutic efficacy of motor imagery (imaginary movements) on the development of motor skills has already been shown in many studies, both in healthy subjects and in pathology. Experiments have shown that in healthy volunteers, the same areas of the brain are activated during motor imagery training as during real movement, but with a slightly lower degree of involvement of the primary motor cortex (M1) and with some difference in topography (Lotze, Halsband 2006; Sharma, Pomeroy 2006; Simmons et al. 2008). Thus,

the movement recreated in a virtual environment is perceived by the brain as a real motor act and is reinforced by positive visual feedback, which in turn activates the undamaged parts of the motor cortex, contributing to the functional restructuring of neural connections and brain plasticity. To our knowledge, the VR environment interface is not currently used in HRVB, however, further development and integration of these technologies cannot be excluded in the future.

Potential levels of cardiorespiratory biofeedback intervention in stroke: opinion

To our knowledge, no systematic research has been undertaken to explore the effects of cardiorespiratory feedback on physical, emotional, cognitive or functional activity levels in stroke survivors. We will discuss the potential effect of this type of biofeedback on selected targets of post-stroke rehabilitation, specifically autonomic regulation, sleep, and emotional regulation.

1. Autonomic regulation

Impaired autonomic regulation, reflected in a predominance of sympathetic activity, is registered in stroke survivors (Hilz et al. 2019). It is yet to be discovered whether interventions (or some specific types of interventions) that target sympathetic activity inhibition or parasympathetic activity promotion might be associated with a better prognosis. Therefore, parasympathetic reflex stimulation by means of HRVB training may reinforce the improvement of autonomic regulation after stroke.

2. Sleep

Sleep disorders are common after stroke and are associated with various adverse outcomes (Seiler et al. 2019).

Sympathetic overactivity including insomnia and obstructive sleep apnoea syndrome is reported in patients with sleep disturbances (Abboud, Kumar 2014). Without timely intervention acute insomnia tends to transform into a chronic form.

Hyperarousal is considered a central element in current etiological models of the insomnia disorder (Kalmbach et al. 2018). Cerebral hyperarousal affects somatic, cognitive and emotional functioning. Common comorbidities of insomnia include anxiety and mood disorders.

Non-pharmacological methods are considered to be the first-choice treatment for stroke-induced sleep problems. HRVB promotes parasympathetic effects via greater vagus nerve traffic, thus helping to initiate and maintain sleep.

3. Emotional regulation

The most common neuropsychiatric disturbances due to stroke are depression, anxiety and apathy (Ferro et al. 2016). About one-third of stroke patients suffer from these conditions resulting in impeded rehabilitation, more disability, a higher risk of stroke recurrence, impaired social functioning, decreased quality of life, and an overall poor prognosis. Moreover, hypothalamic-pituitary-adrenal (HPA) axis and stress response are impaired in depressive patients (Pariante, Miller 2001), and stress axis activity correlates with post-stroke cognitive impairment. According to recent TABASCO study, elevated HPA axis activity predicts lower cognitive outcomes after stroke (Ben Assayag et al. 2017).

The relationship between stroke and depression is described differently by the neuroanatomical and the psychological theory (Gainotti, Marra 2002). The neuroanatomical theory suggests that a left frontal stroke might cause a major post-stroke depression, while the psychological theory considers post-stroke depression to be a result of psychosocial adjustment following stroke.

Depression influences several functional levels, i. e. mood, cognition, and physiology. It provokes a shift in autonomic regulation towards sympathetic effects and decreased HRV (Kemp et al. 2014; Koschke et al. 2009).

Research in a group of subjects with major depressive disorder (MDD) suggests that HRVB may promote a decrease in depressive symptoms (Karavidas et al. 2007). The authors presume that regular exercise of homeostatic reflexes contributes to the treatment of depression even when the changes in baseline HRV are less significant. Several other sources have also reported that HRVB might show efficacy in reducing symptoms of depression and anxiety (Patron et al. 2013; Henriques et al. 2011; Tan et al. 2011).

We hypothesize that HRVB may be a promising non-pharmacological intervention targeting baroreflex function and vagus nerve activity in treating post-stroke depression as well. In addition, HRVB helps a patient to transfer his or her attention

to the process of breathing and muscle relaxation and distract it from maladaptive repetitive thoughts and emotional tension.

HRVB may be a useful adjunct to psychotherapy and antidepressants, bearing in mind that antidepressant medications do not increase HRV and may even decrease it, according to some studies (Bassett 2016; Gorman, Sloan 2000), and considering potential cardiotoxic effects of certain tricyclic antidepressants (Kahl 2018).

Conclusion and future work

HRVB is a relatively new area of research, and its potential in complex therapy of stroke is yet to be discovered. Existing research suggests that it may prove its efficacy in treating a range of medical conditions including cerebrovascular disorders. The prospects of cardiorespiratory biofeedback application in improving a stroke patient's quality of life (including physical, emotional, and cognitive levels) and clinical status require further investigation. The topicality of determining the long-term effect of novel non-pharmacological interventions as an adjunct to conventional therapies is defined by their limitations and significant pharmacological load.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contribution statement

V. V. Kemstach conceived and designed the research, examined scientific sources, and took the lead in writing and proofreading the manuscript. L. S. Korostovtseva, Yu. V. Sviryaev, and A. N. Alekhin contributed to the design of the research. All authors provided critical feedback that helped to shape the research and contributed to writing and correcting the manuscript.

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