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FEATURE ARTICLE

# Heart Rate Variability Biofeedback for Postconcussion Syndrome: Implications for Treatment

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*Heart Rate Variability (HRV) Biofeedback is used to restore balance in the activity of the sympathetic and parasympathetic branches of the autonomic nervous system by increasing or reducing the activity of either. Researchers have postulated that a fundamental cause of refractory postconcussion syndrome (PCS) is physiologic dysfunction that fails to return to normal after concussion. The primary physiologic issues identified have been altered autonomic function and impaired cerebral autoregulation. Evidence has shown that aerobic exercise training increases parasympathetic activity, reduces sympathetic activation, and improves cerebral blood flow so it may, therefore, help to reduce concussion-related physiological dysfunction. The authors hypothesize that HRV biofeedback training will ameliorate PCS by improving autonomic balance as well as cerebral autoregulation, and that there will be a relationship between increased interval variability and postconcussion symptom reduction.*

## HRV Biofeedback: An Overview

Heart Rate Variability (HRV) biofeedback is a growing area of clinical research and is quickly expanding from a treatment for anxiety-related disorders to a method that can improve the health and performance of athletes. Aside from enhancing sport performance, HRV biofeedback is becoming increasingly linked with improving mood, focus, and confidence, as well as reducing anxiety of amateur and professional athletes (Lagos et al., 2008; Lagos et al., 2011; Raymond, Sajid, Parkinson, & Gruzelier, 2005; Strack, 2003). Although it has not yet been directly demonstrated, it is possible that HRV biofeedback will also benefit athletes who do not naturally and spontaneously recover in the days to weeks following a concussion.

HRV biofeedback training is frequently used to decrease the activity of the sympathetic branch of the autonomic nervous system (ANS) associated with the fight or flight response. The reduction in the sympathetic nervous system (SNS) activity is reflected in decreases in heart and respiration rate as well as changes in the distribution of low and high frequency in the beat-to-beat interval variability intervals (RRI) spectrum. While SNS activity is decreasing, the parasympathetic nervous system (PNS), associated with the functions of resting and digesting, is becoming increasingly involved in regulating body functions. More PNS activity and less SNS activity leads to a healthier physiologic state, allowing the body to move towards the direction of health, wellness, and recovery (McKee, 2008; Moravec, 2008; Moss, McGrady, Davies, & Wickramasekera, 2003; Schwartz & Andrasik, 2003; Triposkiadis et al., 2009). Lehrer et al. (2003) have also demonstrated that the benefits of HRV biofeedback (HRV BFB) extend beyond just influencing SNS or PNS arousal. HRV BFB appears to improve reflexes, such as the baroreflexes, that are controlled by the PNS and SNS. The balance between the two systems becomes more tightly regulated, and, where dysfunction exists, the equilibrium is restored.

This review focuses on current research surrounding the physiology of postconcussion syndrome (PCS) and, in particular, the dysfunctions in the cebrovascular and cardiovascular systems, both of which do not naturally return to baseline functioning following injury. The lack of evidence-based treatments to address the physiological dysfunctions associated with PCS is discussed as well. Particular emphasis is placed on the potential for HRV biofeedback to improve the modulatory control of reflexes that impact cardiovascular and cebrovascular regulation, which would have implications for the treatment of PCS.

## PCS and Physiological Dysfunction

The majority of patients with sport-related concussion recover within seven to ten days and nonathletes within the first three months (Gall, Parkhouse, & Goodman, 2004b; Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007; McCrea et al., 2003). There is, however, a considerable minority of athlete and nonathlete patients who continue to experience symptoms beyond this, known as PCS (Levin et al., 1987). According to the World Health Organization, PCS involves a constellation of symptoms that include at least three or more of the following: headache, irritability, insomnia, dizziness, fatigue, concentration difficulty, or memory difficulty. Concussion affects not only cognitive function, but also other physiological systems including the heart and Autonomic Nervous System (ANS) (Leddy et al., 2007). Concussed athletes have exaggerated SNS activity and increased heart rates when compared with controls (Gall, Parkhouse, & Goodman, 2004a; Gall et al., 2004b). Cerebral autoregulation, known as the ability of the brain to maintain constant perfusion pressure in the face of changing systemic arterial pressure during exertion, and cerebral blood flow are disturbed after concussion (Dewitt & Prough, 2003). Given the extent of physiological disequilibrium followed by concussion, it can be argued that there is no such thing as a mild traumatic brain injury.

## Hyperactivation of SNS After Concussion

Increased activity in the SNS is one of the most powerful means by which physiological disequilibrium manifests after a concussion. In response to an injury, such as a concussion, the cardiac sympathetic nerves are activated. If the injury is time-limited, the SNS activity may compensate and the physiological imbalance is resolved. On the other hand, chronic activation of the SNS leads to a sustained state of physiological disequilibrium, which is a key issue for patients with PCS (Leddy et al., 2007). As a result of the chronic SNS activation, the heart begins to spiral into an incoherent state and exaggerate physiological disequilibrium throughout the central and peripheral nervous systems. A necessary goal for PCS treatment, therefore, should be inactivation of the formerly compensatory SNS and the resulting disruption of the body's equilibrium.

## Hypoactivation of PNS After Concussion

Along with hyperactivation of the SNS, PCS may also be accompanied by a decrease in PNS activity. At normal resting conditions, the human heart is modulated more by the PNS than the SNS, with the SNS becoming a major source of cardiac control only after periods of stress or challenge (McKee & Moravec, 2010). In PCS, on the other hand, this relationship is inverted as SNS activity takes a dominant role and PNS activity decreases. In heart failure patients, research has suggested that the lack of PNS activity may be as deleterious as the overactivation of the SNS (Binkley, Nunziata, Hass, Nelson, & Cody, 1991). While further research is needed to explore how reduced PNS activity impacts concussed patients, we postulate that strengthening vagal tone is as important as inhibiting SNS activity during treatment of PCS. Vagal nerve stimulation is currently used for heart failure therapy (McKee & Moravec, 2010); it is likely that future treatments for PCS will consider this modality.

## Balance of Excitation and Inhibition Processes in the Brain

Under normal conditions, a balance exists between excitatory and inhibitory neurotransmission in the brain. In healthy brains, a balance of excitation and inhibition processes is essential for all functions, including representation of sensory information and cognitive processes such as decision making, sleep, and motor control (Cline, 2005). The postconcussion symptoms indicate some disorder in these functions. It seems that PCS is associated with weakness of the inhibitory processes and shifting balance to the excitatory side. Balance of processes in the central nervous system tightly links with balance in the ANS. The baroreflex controls the feedback communication between the body and the brain. According to Lacey and Lacey (1970), the afferent impulse-stream from the baroreceptors strengthens the activity of inhibitory processes in the brain. For each heartbeat, the baroreceptors in the aorta and carotid sinus send a burst of impulses to brain. The high-amplitude 0.1 Hz HR oscillation elicited by HRV biofeedback modulates activity of the baroreceptors. Thus, the HRV biofeedback can amplify inhibition activity in the brain. Additionally, the HRV biofeedback procedures cumulatively increase baroreflex sensitivity (Lehrer et al., 2003).

## Previous Treatments for PCS

The primary forms of treatment of PCS have traditionally involved rest, education, neurocognitive rehabilitation, and antidepressants with little evidence of success (McCrea et al., 2003). PCS patients are generally advised to not engage in exertion while symptomatic from a concussion (McCrory et al., 2005; McCrory et al., 2009). Prolonged rest, however, leads to deconditioning, especially in athletes, and may cause secondary symptoms of anxiety and depression (Willer & Leddy, 2006). Further, traditional treatments of PCS do not address another modulating factor in PCS, persistent physiological disequilibrium. To our knowledge, only one study has examined a method to reduce PCS symptoms by interfering with the physiological disequilibrium caused by the concussion. In 2010, Leddy and his colleagues showed that subsymptom threshold exercise training (STET) reduced symptoms of PCS by improving cerebral autoregulation, improving exercise capacity, and restoring autonomic balance in the body. These findings are congruent with exercise studies, which have demonstrated that aerobic exercise training increases parasympathetic activity, reduces sympathetic activity, and improves cerebral blood flow (Carter, Banister, & Blaber, 2003; Doering et al., 1998).

## HRV Biofeedback for PCS: Rationale

HRV biofeedback is a method that has the potential to interfere with the autonomic decoupling of the ANS and cardiovascular system and improve cerebral autoregulation. If the concussed individual can be trained to reduce activation of the SNS and to increase control of the PNS, it is plausible that the negative consequences of autonomic dysregulation will be reduced or possibly reversed. It remains to be established whether these effects are limited to reducing secondary clinical symptoms such as reactive depression, or whether the effects can extend to reducing the primary constellation of PCS symptoms caused by the concussion. Since cerebral blood flow can also be affected by increasing the PNS control of the cardiovascular system, we hypothesize that HRV biofeedback training may have a direct effect on restoring cerebral blood flow to the brain.

## Future Directions for Study and Treatment

The theory of regulatory and autoregulatory physiological dysfunction as a primary explanation of PCS has implications for treatment. Previous treatments for PCS have focused on identifying and reducing specific symptoms such as anxiety, headache, or improving cognitive variability such as speed of processing, attention, and concentration. Past research, however, has tended to neglect the physiological mechanisms of concussion such as autonomic imbalance and cerebrovascular dysfunction. Future research is warranted to determine whether HRV BFB training ameliorates key physiological components of PCS. Specifically, future research in PCS patients should measure the effects of HRV BFB on variables that impact cerebral autoregulation such as blood pressure, heart rate, cerebral blood flow, pulmonary ventilation, and CO2. In addition, future studies should evaluate the impact of HRV BFB training on the symptoms that reflect disturbed central physiological regulation including HRV, sleep disturbance, headache frequency and duration, irritability, changes in mood, and fatigue. Any research on treatment should also examine the patient's ability to engage in daily life activities such as sport, school, or work, prior to and after treatment, in order to evaluate the extent to which HRV BFB improves postconcussion symptoms as well as quality of life.

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