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SPECIAL ISSUE

A Preliminary Study: Heart Rate Variability Biofeedback for Treatment of Postconcussion Syndrome

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Heart rate variability (HRV) biofeedback (BFB) can be used to reduce activation of the sympathetic nervous system (SNS) and increase activation of the parasympathetic nervous system (PNS). A growing body of research suggests that increased arousal of the SNS contributes to the sustained state of postconcussion syndrome (PCS). It has also been postulated that underactivation of the PNS may also play a role in the postinjury state of autonomic dystonia, wherein the autonomic nervous system is in a state of imbalance and does not return to normal. In addition to autonomic imbalance, patients who are generally advised not to engage in physical exertion until asymptomatic from concussion, are known to experience secondary symptoms of fatigue and reactive depression. Recent research has established that such symptoms can delay the recovery from concussion indefinitely. By addressing both autonomic dysfunction and the secondary symptoms of depression and anxiety, HRV BFB may be an effective treatment for PCS by strengthening self-regulatory control mechanisms in the body and improving autonomic balance. Recent studies have suggested that HRV BFB has a positive impact in reducing stress and anxiety among athletes, and concussed athletes with higher perceived control over their symptoms have been shown to have faster recoveries post-injury. The primary purpose of the following case study was, therefore, to assess the feasibility of implementing HRV BFB with a concussed athlete suffering from postconcussion syndrome (PCS). The second objective was to prospectively examine the impact of ten weeks of HRV biofeedback on refractory postconcussion symptoms. During this pilot case study, the athlete attended 10 weekly sessions of HRV BFB, according to the protocol set forth by Lehrer, Vaschillo, and Vaschillo (2000). After 10 weeks of HRV biofeedback, the athlete exhibited clinically significant improvements in total mood disturbance, postconcussion symptoms, and headache severity. The results suggest that HRV BFB may be a useful adjunctive treatment for PCS, associated with increases in HRV and enhanced cardiovagal activity. Given these findings, a randomized controlled trial is warranted.

Introduction

The neurosurgeon Benjamin Bell wrote in 1787 that "every affection of the head attended with stupefaction, when it appears as the immediate consequence of external violence, and when no mark or injury is discovered, is in general supposed to proceed from commotion or concussion of the brain, by which is meant such a derangement of this organ as obstructs its natural and usual functions, without producing such obvious effects on it as to render it capable of having its real nature ascertained by dissection" (Shaw, 2002). This definition continues to be supported by today's research in two ways. First, it does not imply a short-term deficit that resolves quickly. This is evidenced by the up to 10% of sports-related and 33% of non-sports-related concussive injuries that develop into postconcussion syndrome (PCS). PCS is defined by the World Health Organization's International Classification of Diseases, or ICD-10, as three or more of the following symptoms: headache, dizziness, fatigue, irritability, insomnia, concentration difficulty, or memory difficulty to resolve within a 3–6 week period (Boake et al., 2005). Second, the definition provided by Bell notes that the underlying pathology of the symptoms cannot be ascertained by dissection, thus accurately noting that concussion is a physiological injury, not an anatomical injury, as evidenced by negative structural imaging results (CT, MRI) in concussive injuries (Barth, Freeman, Boshek, & Varney, 2001; Guskiewicz, Ross, & Marshall, 2001).

For over a century, research has demonstrated that brain injury causes cardiac dysfunction, cerebral hypo-perfusion, and heart rate variability (HRV) abnormality (Cushing, 1901; Furgała et al., 2007; Kahraman et al., 2010). Additionally, concussion severity relates directly to HRV statistics supporting the complex bidirectional nature of heart–brain interactions (Gall, Parkhouse, & Goodman, 2004; Goldstein, Toweill, Susanna, Sonnenthal, & Kimberly, 1998; Grippo & Johnson, 2009; Jennings & Zanstra, 2009; King, Lichtman, Seliger, Ehert, & Steinberg, 1997). The correlation between HRV frequency power normalization and brain injury recovery suggests that autonomic nervous system balance is a factor in both the brain insult and a mechanism for concussion resolution (Keren et al., 2005).

Based on the large percentage of concussive injuries that produce PCS, the detrimental effects of PCS on physical, social and psychological health, and the known ineffectiveness of symptom-based treatments to resolve PCS, there is a need to find effective interventions that treat the underlying injury (Leddy, Sandhu, Baker, Sodhi, & Willer, 2012). Given the understanding that concussion is a physiological injury, it is not surprising that recent research and clinical work that apply physiological treatment modalities, such as subsymptom exercise training are being shown to be successful in resolving not only the symptoms involved with PCS but also many of the underlying physiological disequilibria present in concussive injuries (Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007).

The primary goals for this study, therefore, were to establish the safety and potential effectiveness of HRV biofeedback (BFB) for treatment of PCS. Specifically, this study addressed two main research areas. First, it examined the impact of HRV BFB on mood, headaches, and severity of postconcussion symptoms. Second, the impact of HRV BFB on physiological performance as defined by low frequency (LF) HRV, total HRV, and respiration rate was measured. Consistent with previous literature, it was hypothesized that HRV biofeedback would reduce PCS by restoring autonomic balance and cerebral autoregulation and that there would be a relationship between baroreflex gain and symptom reduction.

Background of Patient

The patient in this applied case study was a 42-year-old competitive athlete who suffered her first concussion during practice. The diagnosis of postconcussion syndrome was determined by her primary care physician after clinical examination and was confirmed by an ImPACT test (immediate postconcussion assessment and cognitive testing), which assessed the severity of her postconcussion symptoms. Upon obtaining an initial score of 63 indicating high severity of postconcussion symptoms, the patient was prescribed bed rest and 10 mg of Zoloft. At a follow-up visit, three and a half months following the initial injury, the patient reported an increase of postconcussion symptoms and scored an ImPACT score of 65. Given the lack of evidence-based interventions to address PCS, the physician referred the patient for heart rate variability (HRV) biofeedback training to address physiological dysfunction. At the onset of HRV biofeedback, the patient reported experiencing 14 out of 16 postconcussion symptoms set forth by the World Health Organization (Boake et al., 2005). The patient continued her regimen of bed rest and 10 mg of Zoloft while participating in the biofeedback training.

Method

The 10-week HRV BFB protocol designed by Lehrer, Vaschillo, and Vaschillo (2000) was implemented with the patient. Each session lasted 45 to 60 minutes and included four activities (A: baseline, B and C: biofeedback training, and D: baseline) for five minutes each. Sessions 1, 4, 7, and 10 served as recording sessions. ECG and respiration were recorded during all four tasks. In addition, measures of headache severity, daily life functioning, and mood were obtained during each recording session. At the initial session, the patient's resonance frequency was identified as 0.1 Hz, or six breaths per minute. The resonance frequency is the rate of breathing (and frequency of heart rate oscillation), at which the individual produces the greatest heart rate variability. Sessions 2, 3, 5, 6, 8, and 9 were conducted as training sessions without physiological measures. During training sessions, the patient was taught to breathe slowly but not too deeply at her resonance frequency using abdominal and pursed lip breathing techniques. For homework, the patient was asked to engage in two 20-minute breathing practices each day for ten consecutive weeks. The patient submitted a weekly log of her breathing practice times to the experimenter. All data collection was conducted at approximately the same time of day at the experimenter's therapy office in Manhattan.

Psychometric Measures

The patient completed questionnaires that assessed the severity of postconcussion symptoms, impact of headaches on daily functioning, and mood following the injury.

Rivermead Postconcussion Questionnaire (RPQ). The RPQ is a 16-item measure of PCS severity. The test asks the patient to rate the severity of 16 of the most common published PCS symptoms. In each case, the symptom is compared with how severe it was before the injury occurred. Questions examine the cognitive, somatic, and emotional symptoms concussed patients may experience following their injury. Responses range from 0 (not experienced at all) to 4 (a severe problem), and the maximum score that can be achieved is 64.

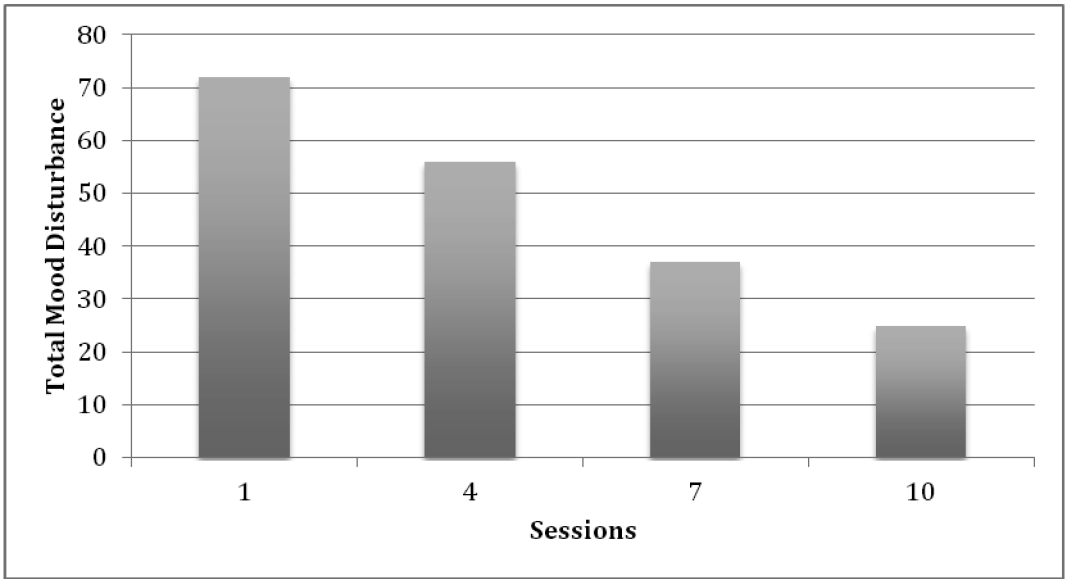

Figure 1. Profile of Mood States (POMS), short form.

Headache Impact Test (HIT-6). The HIT-6 is a scientifically validated short form questionnaire to assess headache impact (range: 36–78). Six questions cover pain severity, loss of work and recreational activities, tiredness, mood alterations, and cognition. A HIT-6 score of less than 48 is interpreted as consistent with little impact; 50–54 shows some impact, 56–58 shows substantial impact, and >60 shows severe impact.

The Profile of Mood States–Short Form (POMS-SF). The 37-item POMS-SF consists of six affective subscales including tension, depression, anger, vigor, fatigue, and confusion. Responses range from 0 (not at all) to 4 (extremely). Scores are interpreted as ranging from a low score indicative of well-being to a higher score associated with distress. Total mood disturbance was calculated by subtracting positive mood scores (vigor and self-esteem) from the sum of negative mood scores (Grove & Prapavessis, 1992).

Physiological Measures

A ProComp Infiniti™ (Thought Technology, Montreal, Canada) system was used to collect cardiovascular data as well as to provide biofeedback training. A blood volume pulse sensor measured cardiovascular activity, including HR and HRV. To record respiration, a respiration strain gauge was placed around the abdomen. As the gauge stretched, the voltage across the tube increased, and relative changes in length were measured with a range of 1–100 units of relative strength.

Data Analysis

Beat-to-beat RR intervals (RRI) and HR were assessed from the BVP signal. Thought Technology software (Montreal, Canada) calculated both the frequency domain measures from both signals. For each dependent variable, data were graphed and visually analyzed to evaluate the effects of the intervention (Barlow & Hersen, 1984). These graphs were interpreted with respect to immediacy and level of change pre- and postintervention, amount of overlapping data points across phases, and changes in slope and/or variability across sessions (Hrycaiko & Martin, 1996; Thelwell, Greenlees, & Weston, 2006).

Results

Mood

As indicated in Figure 1, the athlete showed a clinically significant decrease in total mood disturbance from 72 to 24 between sessions 1 and 10, respectively. Notably, the athlete showed improvements in five out of five negative mood states between session one and session ten on the POMS-SF (Figure 2). The most dramatic change in mood symptoms related to depression. In session 1, the patient scored 25, which is in the severe range for depression. Following 10 weeks of HRV biofeedback, the patient reported a score of 2, which is associated with mild depression. In addition, there was also an increase in vigor, from a score of 5 (low severity) to 13 (moderate severity).

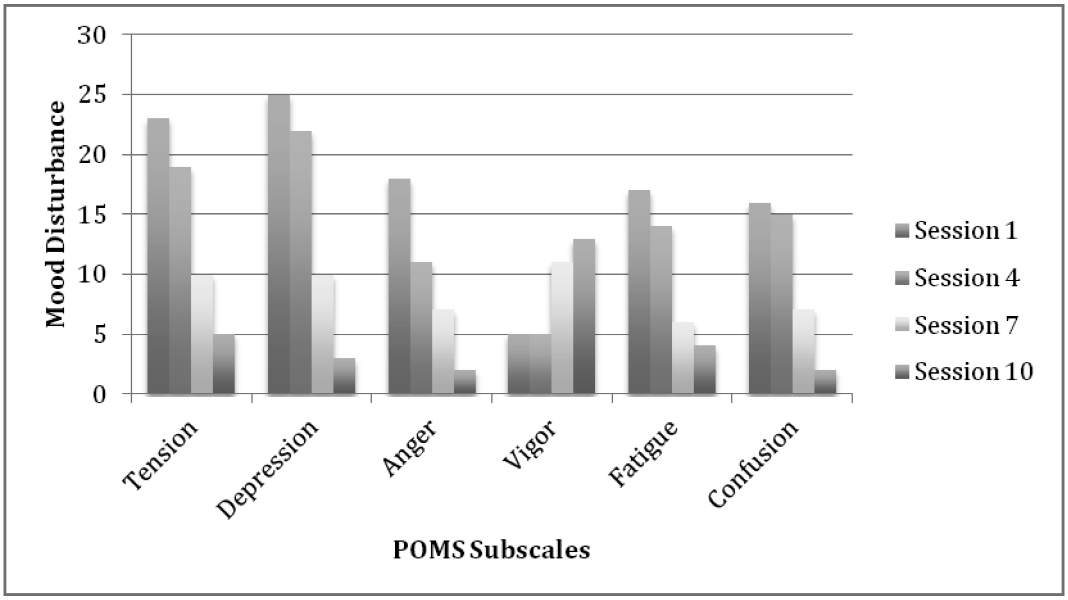

Figure 2. Profile of Mood States (POMS), short form.

Headaches

The impact of headaches on daily functioning decreased from a score of 67 to 48 after HRV biofeedback (Figure 3). A score of 67 in the initial session indicated that the athlete had been experiencing headaches that severely impacted her daily life and disabled her from enjoying family, work, and social activities. After the tenth week of HRV BFB training, the athlete scored a 48, which indicated that her headaches had little to no impact on her ability to function in daily life. A score of 67 in the initial session indicated that the athlete had more severe headaches after three months following injury than the average concussed athletes experiences three days after the concussion (M = 45.4, SD = 7.0; McLeod, Bay, Valier, Lam, & Parsons, 2013).

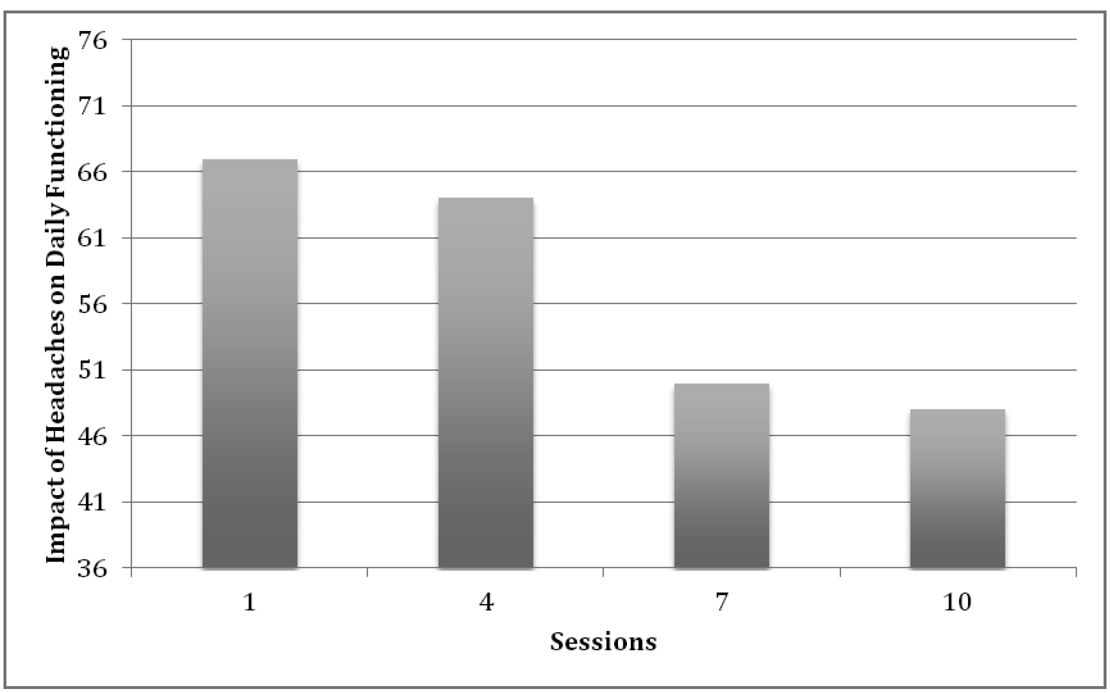

Figure 3. Headache (HIT-6) questionnaire.

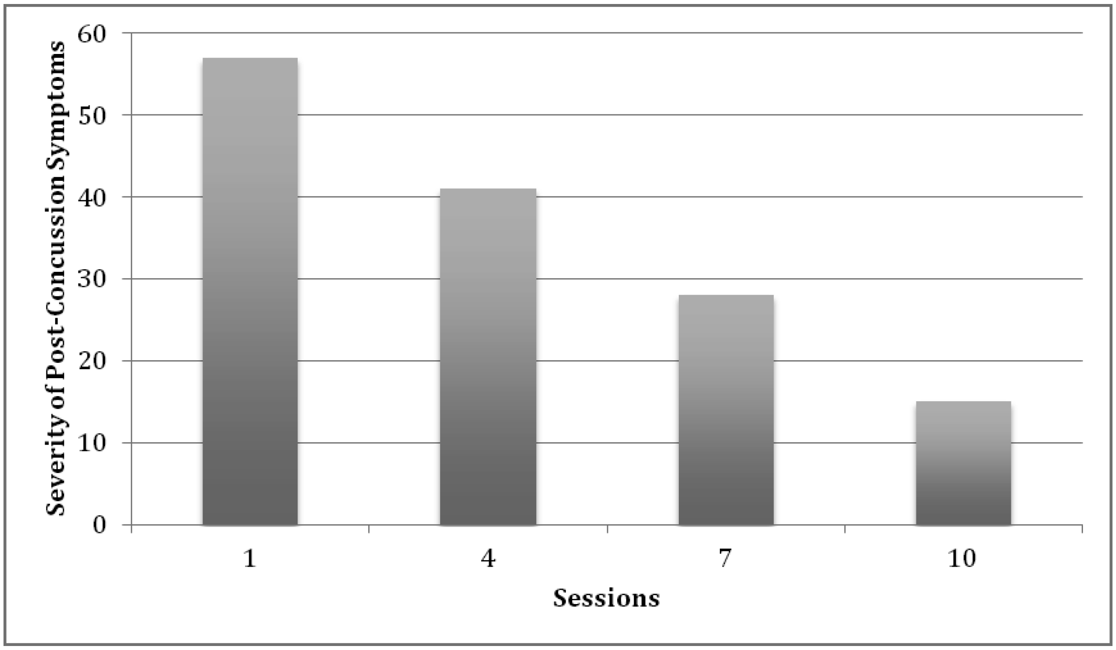

Figure 4. Rivermead Postconcussion Symptom Questionnaire (RPCSQ).

Postconcussion Symptoms

The prevalence of postconcussion symptoms, as measured by the RPCQ, was reduced from 57 to 15 after HRV biofeedback (Figure 4). The initial score of 57, prior to biofeedback training, reflected that the athlete experienced severe postconcussion symptoms. A score of 15 in the tenth session demonstrated that the athlete possessed minimal to mild postconcussion symptoms. In addition, a score of 57 at the initial session denoted that the athlete had more severe postconcussion symptoms than the average athlete with PCS ($M = 19.1$, $SD = 11.9$; Ingerbrigsten, Waterloo, Marup-Jensen, Attner, & Romner, 1998).

Physiological Performance

The data demonstrate that following 10 weeks of biofeedback treatment there is an increase in the patient's total HRV assessed using HR STD DEV in task A (Figure 5), and patient's baroreflex sensitivity assessed using LF HRV in tasks A and C (Figure 6, Figure 7). The amplitude of oscillation in response to ~0.1 Hz breathing strongly correlates with baroreflex sensitivity.

Discussion

Training in HRV biofeedback was followed by: (a) large short term and longer term effects on indices of autonomic control, (b) decreases in mood disturbances and other negative emotional states, and (c) improvements in headaches. The authors of this study believe that the HRV biofeedback provided three therapeutic aspects. First, HRV biofeedback elicited high amplitude oscillations in cardiovascular functions and thereby activated and improved the performance of autonomic reflexes. This finding is consistent with previous studies in which HRV biofeedback training has been shown to increase baroreflex sensitivity (Lehrer et al., 2003). Second, the resonance frequency breathing increased LF HRV significantly, suggesting that sympathetic–vagal balance in the autonomic nervous system was restored. Lastly, high amplitude oscillation in heart rate, caused by resonance in the baroreflex closed loops, modulates the brain through afferent firing from baroreceptors, and restores the balance between inhibition and excitation processes in the brain.

Limitations and Future Directions

As this was a preliminary and clinical case study, our results do not lead to a definitive conclusion. The absence of a control group allows the possibility that the patient's improvement was due to placebo effect or nonspecific factors rather than the intervention, or that the results will not be replicated in all cases. We believe that spontaneous recovery, however, is unlikely during the 10 weeks of HRV biofeedback, since the patient was symptomatic for many months prior to the HRV biofeedback program and did not improve after 1 to 3 months of standard treatment. Furthermore, the patient's physiological and emotional

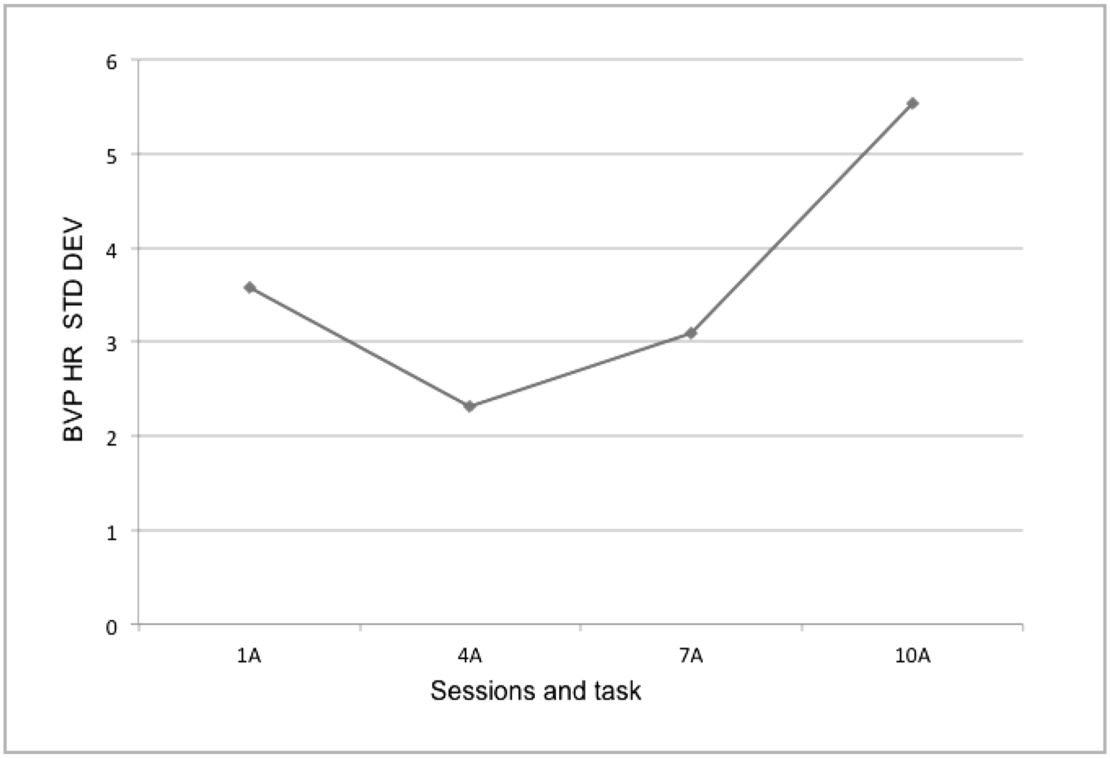

Figure 5. Heart rate standard deviation (HR STD DEV).

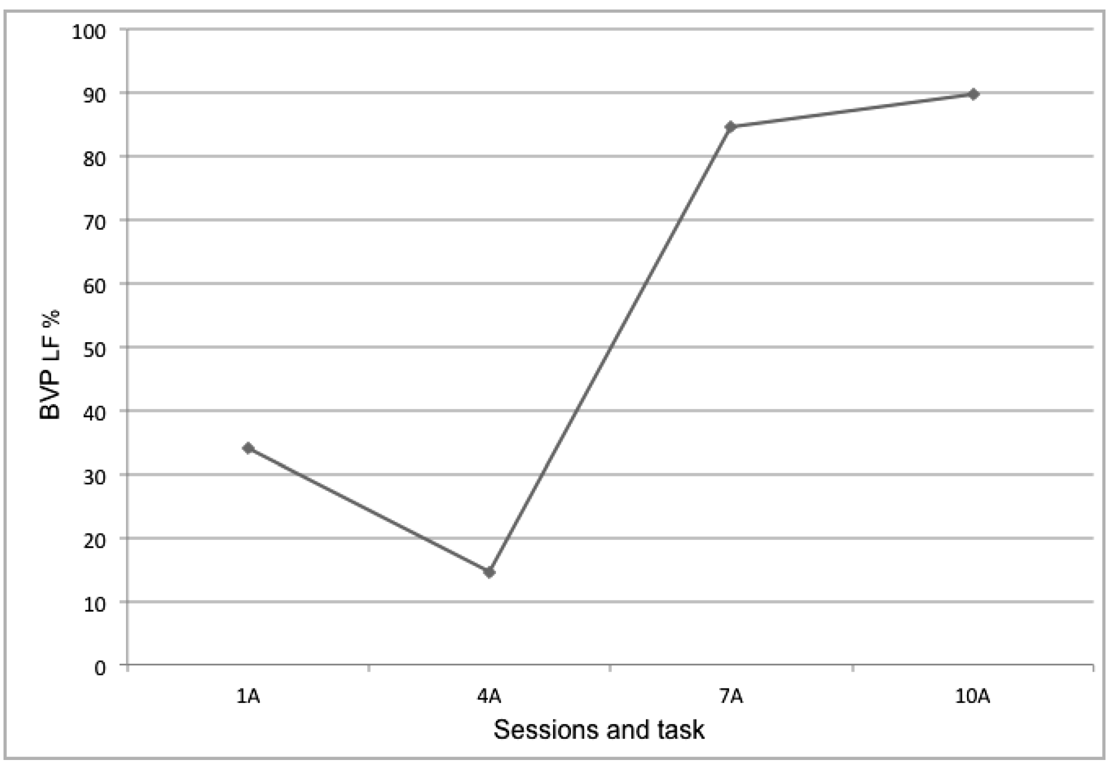

Figure 6. Low frequency heart rate variability (LFHRV).

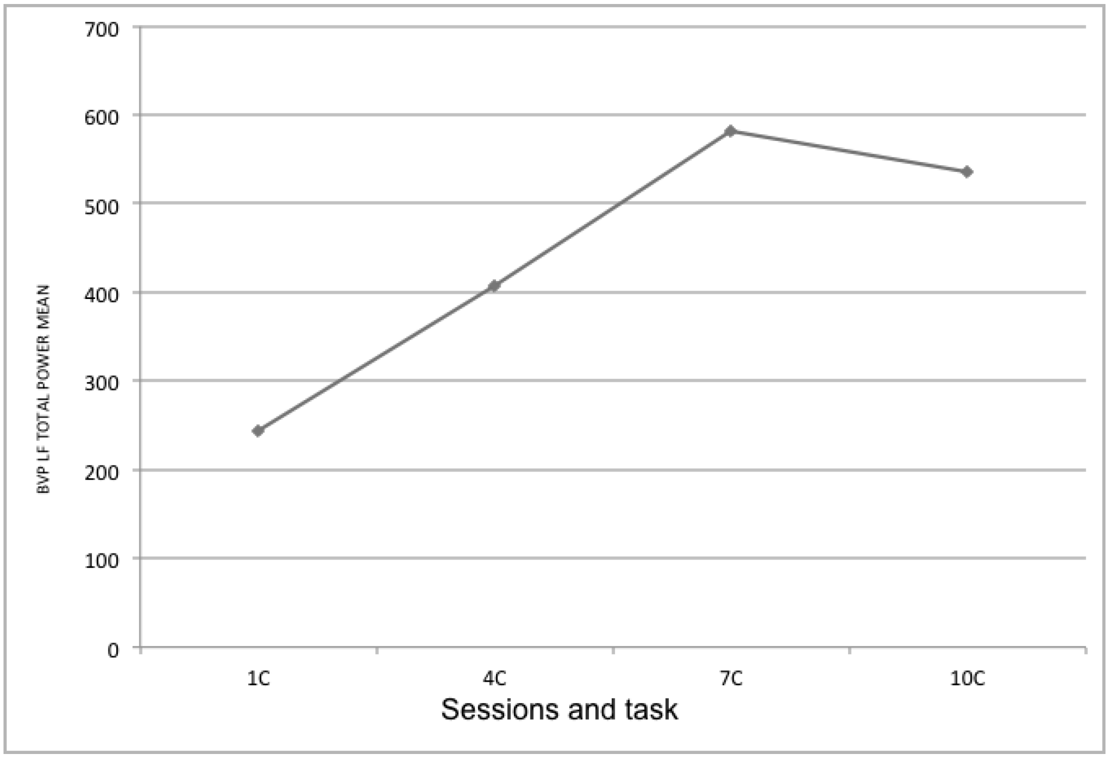

Figure 7. Baroreflex sensitivity.

symptoms improved concomitantly after the HRV biofeedback.

An additional limitation of this study is that the mechanisms by which neurocognitive symptoms of PCS were impacted by HRV biofeedback were not adequately investigated in this study. Assessing the impact of HRV biofeedback on attention and cognitive processing speed could reveal much about the role of the vagus nerve and baroreflex gain in mediating cerebrovascular changes. Thayer and Brosschot (2005) have noted that the autonomic nervous system includes the afferent interoceptive arm and the efferent visceral motor arms of the sympathetic and parasympathetic nervous system as well as higher level integrative and regulatory neural networks found at various levels in the brain. It is possible that the disequilibrium in these integrative and regulatory neural networks maybe related to the source of autonomic dystonia that characterizes PCS. There is a growing consensus that one fundamental cause of refractory PCS is physiological dysfunction that fails to return to normal after concussion (Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007). The frequent comorbidity of PCS and major depression disorder (Belanger & Vanderplog, 2005) and evidence of shared exacerbated activity of excitation and depressed inhibition processes in the brain (Leddy et al., 2007) further highlights a potential dysfunction of these neural circuits. Indeed, one of the patient's most dramatic changes in PCS symptoms was the significant improvement in depression symptoms. This supports the hypothesis that the effects of HRV biofeedback on these higher-level brain functions may be involved in symptom relief in PCS. Future studies may benefit from including quantitative electroencephalogram measures to explore the role of the vagus nerve and baroreflex sensitivity in mediating cerebrovascular changes.

In summary, despite the limitations inherent in this small case study, HRV biofeedback shows promise for the adjunctive treatment of PCS. Our findings demonstrate that compared to symptom management intervention programs that modulate symptom severity, for example antidepressant medications and sleep aids, HRV biofeedback is a safe and effective intervention that directly addresses at least some of the fundamental physiological dysfunction that occurs in the concussed patient. Additional assessment of this intervention is warranted in larger, controlled trials.

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