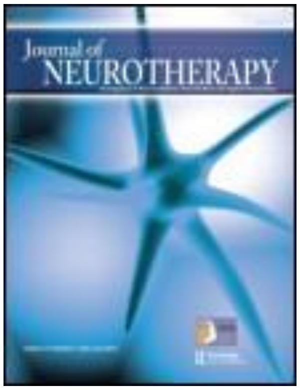

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THE EFFECTS OF HEART RATE VARIABILITY TRAINING ON SENSORIMOTOR RHYTHM: A PILOT STUDY

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Heart rate variability (HRV) training and EEG Biofeedback are techniques used to improve neurological disorders in both clinical and optimal performance populations. HRV training uses combined respiration and heart rate biofeedback to achieve synchrony between the changes in breathing and heart rate. This specific signature of synchronization of breathing and heart rate changes appears to correlate with a relaxed state and cognitive clarity. HRV may provide a promising index for both physical and emotional stress. Improvements in mental processing (Thayer, Hansen, Saus-Rose, & Johnson, 2009) and emotional stability (Applehans & Lueken, 2006) have been demonstrated as a result of HRV training. A similar mental state is the target of EEG biofeedback training when parameters are set to increase sensorimotor rhythm (SMR). SMR is usually trained using the frequency band 12–15 Hz. These frequencies are called SMR only when they are produced across the sensorimotor strip (C3, Cz, C4). In other locations, 12–15 Hz is simply called beta. SMR production has been closely linked to a state of calm, relaxed focus (Sterman, 1996). This article proposes that HRV training may be associated with increased levels of SMR. Preliminary data have been collected for 40 clients. Twenty clients were athletes training to improve performance, and 20 clients were from a clinical population aiming to increase SMR as a part of their program. A 3-min sample of EEG baseline data was compared to a 3-min sample of EEG data collected during HRV training. Mean microvolt values were collected for SMR during both the baseline recording and during the HRV training. *T*-test results show that there was a statistically significant increase in SMR during HRV training as compared to baseline ($p < .001$). This suggests that increased HRV leads to increases in production of SMR.

INTRODUCTION

Heart rate variability (HRV) training and EEG Biofeedback are techniques that have been used to improve functioning in people with neurological disorders, such as attention deficit hyperactivity disorder (ADHD), as well as to optimize performance in athletes. HRV is defined as the changes in the time interval between one beat of the heart and the next. HRV can measure the balance between the sympathetic and parasympathetic branches of the autonomic nervous system, reflecting the influence of each branch on heart rate. Vaschillo, Lehrer, Rishe, and Konstantinov (2002) called the low-frequency range 0.05–0.15 Hz, which generally corresponds to five to six breaths per minute, and in the low-frequency range the participant assumes respiratory sinus arrhythmia (RSA). RSA describes the relationship between heart rate changes and breathing, increased heart rate during inhalation, and decreased heart rate during exhalation. Breathing is intimately linked to heartbeat, and HRV amplitude varies radically with breathing frequency. Generally, breathing between five and six breaths per minute yields a shift toward

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the low-frequency range, but this is not always the case. Resonance found between these frequencies for breathing and heart rate variations relate to the heart rate closed loop of the baroreflex system, through which blood pressure changes are regulated. There are multiple factors that contribute to HRV. These factors include contribution from tonic and reflexive changes in the central nervous system and reflex related changes in blood pressure, carbon dioxide, and oxygen levels that are detected by both chemoreceptors and baroreceptors. Traditionally, baroreflex control of heart rate has been described by a curve relating R-R interval or heart rate to arterial pressure. This relationship implies that stimulation of baroreceptors with increases in pressure leads only to decreases in heart rate, or an increase in R-R intervals and unloading of the baroreceptors with decreases in pressure leads only to increases in heart rate. This specific signature of synchronization between breathing and heart rate changes has been observed to correlate with a more relaxed state and with cognitive clarity. Improvements in cognition (Vaschillo et al., 2002) and emotional constancy (Applehans & Lueken, 2006) have been demonstrated as a result of HRV training. Various studies have demonstrated the effectiveness of HRV training on mental and physical health. Lehrer, Vaschillo, and Vaschillo (2004) showed improvements in people with asthma who were able to reduce the amount of medication they used. Zucker, Samuelson, Muench, Greenberg, and Gevirtz (2009) demonstrated decreased symptoms in posttraumatic stress disorder. Other researchers have looked at improvements in hypertension (Grossman, Grossman, Schein, Zimlichman, & Gavish, 2001; Lehrer, 2007) and symptoms of depression (Karavidas et al., 2007) following HRV training. In addition, higher HRV predicts better information-processing efficiency and working memory capacity in 28- to 65-year-olds (Gevirtz, 2011).

A review of the literature on HRV and athletics reveals a possible link between HRV and improved sports performance. Research by Lagos et al. (2008) demonstrated that, when training an athlete at a resonant frequency of 0.1 Hz, the athlete showed a more stable index of physical and emotional stability. Note that 0.1 Hz equates to six breath cycles in 1 min, which is 10 s per breath. HRV biofeedback has aided golfers in reducing competition anxiety (Lagos et al., 2008). In this case study, the golfer achieved his personal best score in golf and remarked feeling less anxious following HRV training.

EEG biofeedback training to increase sensorimotor rhythm (SMR; 12–15 Hz across the sensorimotor strip at C3, Cz, C4) has been a target of training to improve cognitive functioning for neurological disorders. SMR has been closely linked to a quieting state of calm, relaxed focus (Sterman, 1996). In 2009, Thompson and Thompson developed the systems theory of neural synergy, which outlines a link between HRV and brain function. In this theory, Thompson and Thompson proposed that Neurofeedback (NFB) done at a central location to encourage healthy EEG patterns will affect not just activity at Cz but whole neural networks (Thompson & Thompson, 2009). This NFB is combined with Biofeedback (BFB), in particular, HRV training. The NFB and BFB work synergistically to aid clients in reaching their optimal level of performance. This is possible because there are underlying connections between the heart and the brain; in particular, the vagus nerve has afferent connections that go to the central nervous system in the brain stem (the nucleus solitaries in the medulla) and connections from there to the cortex. This provides a neuroanatomical rationale for doing NFB plus BFB to have the dual influence on functioning. In addition, there have been studies looking at a link between HRV training and brain function; for example, Thayer, Hansen, Saus-Rose, and Johnson (2009) found that higher HRV is associated with greater frontal inhibitory tone.

The neurovisceral integration system of cardiac vagal tone combines autonomic, attentional, and affective systems into an integrative functional team. This neural network can be identified by HRV. High HRV is associated with greater prefrontal inhibitory tone. Without inhibition, the systems reduce their response to environmental changes. In this article, we discuss a link between HRV training and SMR.

We propose that training for increased HRV, even when NFB is not being done simultaneously, can lead to increased levels of SMR activity.

At the ADD Centre, it is common practice to combine EEG-biofeedback with physiological biofeedback, including respiration and heart rate training. While working with clients at the ADD Centre, the authors noticed that many clients, including athletes, were showing increased SMR during sessions when they were training to achieve synchrony between respiration and heart rate changes (HRV training). This observation lead to the hypothesis that HRV training may enhance increases in SMR.

METHOD

The data were collected at the ADD Centre under the supervision of Dr. Lynda Thompson and Dr. Michael Thompson. Forty clients ($N = 40$) were included in this study. Twenty clients were athletes training to improve performance, and 20 clients were from a clinical population (such as those with ADHD and/or anxiety) aiming to increase SMR as a part of their program. The age range in this study was 16 to 61 years, and there were 17 females and 23 males. The first step was to record a 3-min baseline EEG at Cz referenced to the left ear. During this recording, we measured SMR (12–15 Hz) as well as a higher frequency activity (52–58 Hz) that shows EMG (muscle artifact) on the EEG. Next we recorded 3 min of EEG data during HRV training. During the HRV training, the client is instructed to use effortless diaphragmatic breathing to achieve synchrony between respiration and heart rate, which is usually done when breathing at approximately six breaths per minute. Data were recorded during the first 3 to 5 min of training. Clients were instructed to breathe in for 3 to 4 s and exhale for 5 to 6 s. Alternatively, they were told to follow their heart rate. As the heart rate increased, the clients were told to breathe in, and as their heart rate decreased they were instructed to exhale. No data were recorded after the first session in order to control for SMR training contamination. Clients that could produce resonant frequency within the first session were included in the study. The periods of HRV training were comparable across subjects. The training screen used for HRV training can be seen in Figure 1. Note the variation in the RSA breathing as the client practices their HRV training and the way

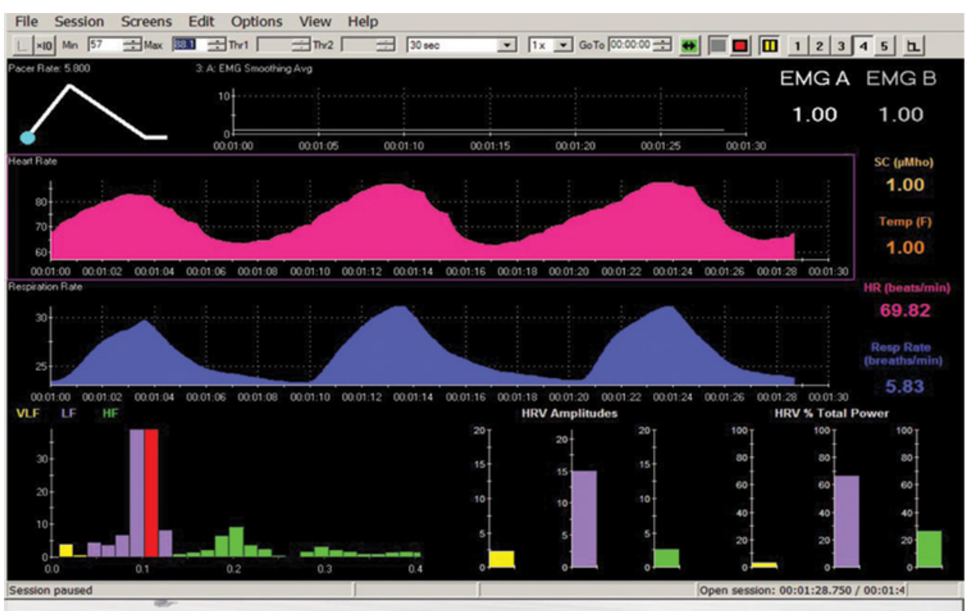

FIGURE 1. Training screen used for heart rate variability. (Color figure available online.)

covariation between heart rate and respiration relates to low frequency. We only included clients in this study who were able to achieve this synchrony. For this reason, only clients whose peak frequency heart rate was between .05 and .15 were included. All of the clients in this study achieved peak frequencies between .08 and .12. This corresponds to approximately five to seven breaths per minute.

For both assessment and HRV training we used Thought Technologies equipment (The Biograph Infiniti 8-channel unit and the Biograph Infiniti software) plus screens from Setting Up for Clinical Success (available from the Biofeedback Foundation of Europe). This system allowed us to record breathing, heart rate, and EEG at the same time. The breathing was monitored using a respiration belt with stretch sensors placed around the subject's abdomen in order to measure diaphragmatic breathing. Heart rate was measured with a plethysmograph (blood-volume-pulse sensor) held in place against the thumb using self-adhesive tape. EEG was measured using silver-silver chloride electrodes with a sampling rate of 256 samples per second. Impedance was checked before each session. The goal was to have it below 5 kOhms and the readings within 1 kOhm, but in some subjects training proceeded as long as it was below 10 kOhms and all 3 readings were within 1 kOhm.

RESULTS

T-tests were used to determine statistical significance. Mean microvolt values were collected for SMR during the baseline recording and during the HRV training. SMR magnitude (mean amplitude) during baseline was 4.36 microvolts and SMR mean during HRV was 4.73 microvolts. First we looked at the change in SMR from baseline to HRV training and found that there was a statistically significant rise in amplitude ($p < .001$). To be sure that this increase in SMR was not simply due to the effect of muscle tension (EMG effects on the EEG) we also checked if the change in the frequencies that reflect EMG from baseline to HRV training was significant by completing a second t test

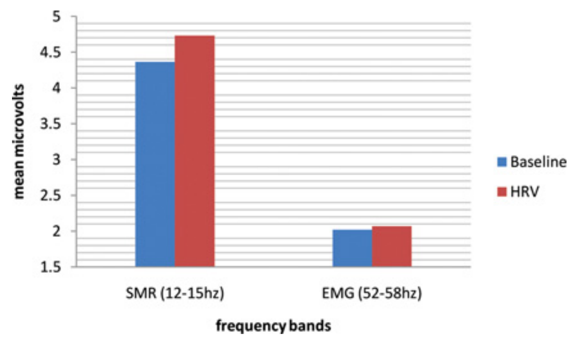

FIGURE 2. Amplitude changes (measured in microvolts) in the sensorimotor rhythm (SMR) and muscle tension (EMG) before and after heart rate variability (HRV) training. (Color figure available online.)

comparing EMG during baseline recording to EMG during HRV training, and the difference was not statistically significant ($p > .2$). This means that there was a true increase in SMR independent of any increase in muscle tension from baseline to HRV training. See Figure 2 for a graphical representation of the results. An analysis of variance was used to determine whether the following variables were moderating factors. We compared males with females, teenagers with adults, and athletes with the clinical population. In all cases there were no significant differences in the results. This provides further evidence that the HRV training produces an increase in SMR across all the populations sampled (males and females older than age 16 whether they were athletes or in the clinical population).

DISCUSSION

The preliminary results suggest that HRV training can lead to increases in SMR. These results have implications in the clinical setting. It lends support to the hypothesis that clients with neurological disorders such as ADHD, seizure disorders, and Asperger's syndrome who are working toward increasing SMR may benefit from combining this neurofeedback training with HRV training. Permanent changes in SMR can be seen in varying amounts of time depending on age and purpose for training (improvements in symptoms of a clinical disorder or optimal performance). The clinic recommends

40 sessions with progress assessments at 20 sessions and after 40 sessions. Changes can be seen as early as the first 20 sessions. This combination of biofeedback and neurofeedback may lead to better clinical outcomes, possibly in less time.

HRV training gives the athletes more flexibility in controlling their autonomic nervous systems and thereby allows them to better regulate their emotional states during sports performance, which is a critical tool during a high stress performance. Breathing at one's resonant frequency can help maintain a calm, relaxed focus in the body and mind. SMR has been closely linked to a mental state of calm, relaxed, and focused concentration (Thompson, Thompson, & Reid, 2010). One might also hypothesize that the increased level of concentration required for HRV training may also be a contributing factor to the increase in SMR. This study suggests that, by training HRV and SMR, athletes can obtain synergy between body and mind and thereby reach a more ideal performance state. Alternatively, it could be hypothesized that the causal effect of SMR increase could be due to the participant sitting still and being relaxed regardless of HRV training. However, this is unlikely because the client was also sitting still during the baseline EEG recording and the EMG change was not significantly different. Future research could look at a regression analysis demonstrating a positive association between HRV magnitude and SMR amplitude, which would enable a more reliable interpretation of causality. One of the limitations of the study is using Blood Volume Pulse instead of EKG. Use of EKG would allow further analysis of the Inter Beat Interval, which is more accurate.

Another area of future research could be to investigate how this study relates to CO_2 percentage in exhalation. To address this, a capnometer could be utilized to look at the O_2 cascade. Carbon dioxide plays a large role in oxygen transport from the blood to the cells of the brain and body. Higher levels of CO_2 leads to an immediate drop in blood and extracellular fluid pH levels through the formation of carbonic acid, this allows the hemoglobin to more efficiently distribute its oxygen to meet local metabolic demands. Lower levels of CO_2, as a result of lower metabolism, leads to blood vessel constriction and to higher levels of blood and extracellular fluid pH, thus permitting oxygen and glucose to go elsewhere where metabolic requirements are greater. This is considered healthy breathing and should be considered in future research. The slight shifts in CO_2 chemistry associated with overbreathing may cause physiological changes such as hypoxia (oxygen deficit), cerebral vasoconstriction, heart constriction, blood pressure and increased pH.

Based on the preliminary results of this study, practicing HRV training with clinical populations and with athletes is associated with increases in SMR at the central location (Cz), which is associated with a relaxed, attentive state. Future research could investigate the combination of SMR training with HRV training as an effective method or intervention for working with both clinical populations and athletes to ameliorate symptoms and optimize performance.

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