Non-pharmacological Intervention for Chronic Pain in Veterans: A Pilot Study of Heart Rate Variability Biofeedback

Melanie E. Berry, MS, United States; Iva T. Chapple, MD, United States; Jay P. Ginsberg, PhD, United States; Kurt J. Gleichauf, PhD, United States; Jeff A. Meyer, PhD, United States; Madan L. Nagpal, PhD, United States

ABSTRACT

Objective: Chronic pain is an emotionally and physically debilitating form of pain that activates the body’s stress response and over time can result in lowered heart rate variability (HRV) power, which is associated with reduced resiliency and lower self-regulatory capacity. This pilot project was intended to determine the effectiveness of HRV coherence biofeedback (HRVCB) as a pain and stress management intervention for veterans with chronic pain and to estimate the effect sizes. It was hypothesized that HRVCB will increase parasympathetic activity resulting in higher HRV coherence measured as power and decrease self-reported pain symptoms in chronic pain patients.

Study Design: Fourteen veterans receiving treatment for chronic pain were enrolled in the pre-post intervention study. They were randomly assigned, with 8 subjects enrolled in the treatment group and 6 in the control group. The treatment group received biofeedback intervention plus standard care, and the other group received standard care only. The treatment group received four HRVCB training sessions as the intervention.

Measures: Pre-post measurements of HRV amplitude, HRV power spectrum variables, cardiac coherence, and self-ratings of perceived pain, stress, negative emotions, and physical activity limitation were made for both treatment and control groups.

Results: The mean pain severity for all subjects at baseline, using the self-scored Brief Pain Inventory (BPI), was 26.71 (SD=4.46; range=21-35) indicating a moderate to severe perceived pain level across the study subjects. There was no significant difference between the baseline and control groups at baseline on any of the measures. Post-HRVCB, the treatment group showed marked and statistically significant (1-tailed) increases over the baseline in coherence ratio (191%, P=.01), negative emotions (49%, P=.04) and marked, significant (1-tailed) reduction in pain ratings (36%, P=.02), stress perception (16%, P=.02), negative emotions (49%, P=.001), and physical activity limitation (42%, P=.001). Significant between-group effects on all measures were found when pre-training values were used as covariates.

Conclusions: HRVCB intervention was effective in increasing HRV coherence measured as power in the upper range of the LF band and reduced perceived pain, stress, negative emotions, and physical activity limitation in veterans suffering from chronic pain. HRVCB shows promise as an effective non-pharmacological intervention to support standard treatments for chronic pain.

INTRODUCTION

Physical and mental health problems are common in veterans suffering from chronic pain. Standard therapy for chronic pain is heavily dependent on the use of opioids and opioid receptor binding compounds. The use of opioids poses a number of risks to patients ranging from psychological addiction to physical side effects such as intolerance, constipation, and nausea.1 Seal conducted a national-level study that found that veterans with mental health diagnoses are significantly more likely to receive prescription opioid for pain-related conditions than veterans with no mental health diagnosis.2 Non-pharmacological therapies that reduce the usage of opioid medications would be a significant benefit to all chronic pain patients.

Lowered heart rate variability (HRV) has recently been found to be associated with increased pain perception in patients suffering from chronic pain conditions.3,4 As a measure of the interplay between the excitatory sympathetic and the inhibitory parasympathetic nervous systems, HRV is widely considered an indication of healthy neurocardiac function. It reflects heart-brain interactions and autonomic nervous system (ANS) dynamics.5,6 In spectra analysis of HRV, the high-frequency (HF) band (.15-0.40 Hz) reflects the efferent parasympathetically driven oscillations in heart rate associated with breathing and respiratory sinus arrhythmia. Low-frequency (LF) HRV (.04-0.15 Hz) can be influenced by both parasympathetic and sympathetic influences. Parasympathetic influence (coherence) predominates under conditions of slow breathing.6 Sympathetic activation increases under conditions of physical activity and significant psychological and physiological challenge.7 Low HRV in any of the frequency bands is linked to diminished emotional and cognitive self-regulation8 and associated...
with multiple psychopathologies, including panic disorder and posttraumatic stress disorder (PTSD).9

Heart rate variability coherence biofeedback (HRVCB) is a non-pharmacological treatment that has applications in the amelioration of chronic pain by influencing afferent vagal activity, which is associated with increased HRV10 and inhibition of pain pathways influencing afferent vagal activity, which is associated applications in the amelioration of chronic pain by (HRVCB) is a non-pharmacological treatment that has

HRVCB training was done by an HRVCB professional

a post-training assessment of pain, stress, and HRV. The

four biofeedback training sessions and was followed by

emotional state. The technique was practiced during

baseline HRV assessments. These were followed by

pre-training baseline assessments of perceived pain

≥ (BMI

reporting substance abuse or who were overweight

diabetes, traumatic musculoskeletal system damage,

heart disease,26,27 and PTSD.28,30

This study seeks to determine the effectiveness of

HRVCB in increasing HRV, particularly in the LF band and the resulting increase in afferent vagal traffic as a pain management intervention for veterans with chronic pain and to estimate the effect size of the intervention. It is hypothesized that HRVCB aimed at improving parasympathetic activity will decrease self-reported pain symptoms and functional status in chronic pain patients.

METHODS
Participants and Study Design
All study participants were patients diagnosed with chronic pain at the Wm. Jennings Bryan Dorn VA Medical Center. The study was a pre-post intervention study of 14 veterans randomly assigned to a treatment group and a control group. The treatment group (n=8) received instruction in a self-regulation technique that is known to increase HRV coherence coupled with computer-based HRVCB (emWave Desktop, Institute of HeartMath, Boulder Creek, California) plus standard care for chronic pain; the control group (n=6) received standard care without additional training.

Potential study participants were not recruited if they indicated regular use of medications known to affect ANS function or pain perception, including antidepressants, benzodiazepines, anti-inflammatory medications and beta-blockers, 2 weeks prior to participation. Subjects reporting diagnoses of rheumatism, diabetes, traumatic musculoskeletal system damage, chronic neurological and endocrinology syndromes, hypertension, or coronary artery disease and those reporting substance abuse or who were overweight (BMI ≥30) were also not recruited.

Following consent, all study participants received pre-training baseline assessments of perceived pain levels using the Brief Pain Inventory (BPI) of perceived stress levels using the Perceived Stress Scale (PSS) and baseline HRV assessments. These were followed by instruction in the self-regulation technique called Quick Coherence, which incorporates controlled breathing and the self-induction of a positive or neutral emotional state. The technique was practiced during four biofeedback training sessions and was followed by a post-training assessment of pain, stress, and HRV. The HRVCB training was done by an HRVCB professional during weekly sessions over a 4-week period. Control subjects simply returned to the lab for a follow-up evaluation 4 weeks after the initial assessment.

Measures
1. Perceived pain: The pain scores were recorded using the BPI (Short Form), a self-report perceived pain numeric rating scale (NRS) with 0 indicating the worst pain a patient could imagine. The validity and reliability of the BPI have been extensively documented.31-34
2. Perceived stress: The stress scores were recorded using the PSS, a self-report perceived life stress instrument whose validity and reliability have been well established.26,35
3. Negative emotion and physical activity limitation were assessed using subscales within the BPI instrument. These subscales have been shown to have a high degree of validity and reliability.36
4. HRV measurements were carried out as reported previously.18 Resting HRV was measured for 10 minutes during first baseline recording before any training in the HRVCB technique took place. The post-training resting HRV was also recorded for 10 minutes.

Cardiac coherence was calculated using the method of McCraty,6 as described previously.28 Coherence is characterized by a narrow, high-amplitude, easily visualized peak that falls into the upper LF or lower HF bands (0.09-0.14 Hz). Coherence is operationalized by identifying the maximum peak in the 0.04 Hz to 0.26 Hz range (the frequency range within which coherence and entrainment can occur), calculating the integral in a window 0.030 Hz wide centered on the highest peak in that region, then calculating the total power of the entire spectrum. The coherence ratio is formulated as coherence = peak power / (total power – peak power). This method provides an accurate measure of coherence that allows for the nonlinear nature of the HRV waveform over time.

Statistical Analysis
Baseline and post-training comparisons between the treatment and control groups were made using independent t-tests. Pre-post changes in measures were analyzed with dependent t-tests in the HRVCB group. Between subjects effects of HRVCB were analyzed using analysis of covariance (ANCOVA), with pre-training levels used as covariate. Results were considered significant when P values (1-tailed) of less than .05 were achieved. All data analysis was done using SPSS 19.0 statistical software (IBM Corp, Armonk, New York).

RESULTS
Fourteen veterans were enrolled in this study. Eight participants were enrolled in the treatment group and completed the HRVB intervention. Six veterans completed the control group regimen. The demographic
characteristics of the sample are displayed in Table 1. The pre and post values of the measures for both groups are presented in Table 2. The mean pain severity at baseline, as scored by BPI, was 26.71 (SD=4.46; range=21-35), indicating moderately severe pain symptoms. There were no significant differences (2-tailed) at baseline between the treatment and control groups on coherence ratio, pain perception rating, perceived stress, negative emotion, or activity limitation (Table 2).

The impact of HRVCB training on the measures of interest is presented in Table 3. The treatment group showed significant (1-tailed) increases over the baseline in coherence ratio (191%; \( P=.04 \)). The HRVCB group also showed a marked significant reduction in pain ratings (36%, \( Pc=.001 \)), stress (16%, \( P=.02 \)), negative emotion (49%, \( Pc=.001 \)), and limitation of physical activity (42%, \( Pc=.001 \)).

Treatment effects were analyzed with ANCOVA of post scores by group, using pre scores as the covariate. The treatment group was significantly lower than the control group on all outcome measures post-HRVCB training (all \( P < .05 \)). The between-group analysis of pre-post changes in variables of interest (coherence, pain rating, stress perception, negative emotion, and physical limitation) between baseline and posttreatment is shown in Figure 1 (A-E). Figure 2 shows the baseline values compared to their posttreatment values in the treatment group.

**DISCUSSION**

This pilot study demonstrates that HRVCB is both feasible and effective in increasing cardiac coherence and reducing perceived pain, stress, negative emotions, and physical activity limitations in veterans suffering from chronic physical pain due to injuries. Many veterans who have chronic pain use avoidance strategies to dampen the intensity of pain in their lives. This avoidance is most clearly seen in behaviors and movement. Painful activities are avoided in an attempt to decrease the overall experience of pain. Though behavioral avoidance strategies can lessen pain in the short term, it can also cause long-term problems and decreases in quality of life.37

Previous studies have also shown increased self-awareness to be useful in coping with pain.38 An aspect of the self-regulation training included teaching the veterans to be more aware of their feelings and emotions and to instruct them that when they are feeling stressed or unproductive to use the self-regulation technique to shift into a more coherent state and neutralize these counterproductive feelings. Conversely, research examining the effects of cognitive avoidance strategies has shown that “not thinking about the pain” can have a rebound effect and result in exacerbation of several pain and anxiety processes.39 Our pilot study suggests that HRVCB combined with simple self-regulation techniques reduces cognitive avoidance of physiological processes and encourages tolerance of pain perception. In addition to increasing awareness of internal psychophysiological processes, instruction in these techniques combined with computer-based HRVCB works in concert with well-established behavioral medicine techniques for coping with pain.

| Variable Pre-Post Changes of Measures in the Active HRVCB Treatment Group, Mean (SD) |
|-----------------------------------------------|

| Variable | Pre | Post | % Change | Corr_Coeff (P) | t-valueb | P | 95% CI of difference |
|----------|-----|------|----------|---------------|----------|---|----------------------|
| Coherence | 0.22 (0.19) | 0.42 (0.24) | 191 | -0.05 (0.45) | -1.8 | .05 | (-0.5, 0.0) |
| Pain | 27.1 (4.9) | 17.3 (4.6) | -36 | 0.52 (0.09) | 6.0 | <.001 | (6.0, 13.7) |
| Stress | 24.4 (5.8) | 20.4 (6.1) | -16 | 0.70 (0.03) | 2.5 | .02 | (0.2, 7.84) |
| Neg_Emotion | 35.0 (3.5) | 19.8 (10.4) | -49 | 0.53 (0.08) | 4.8 | <.001 | (7.7, 22.8) |
| Activ_Red | 34.1 (4.6) | 19.9 (10.4) | -42 | 0.22 (0.30) | 3.9 | <.001 | (-16.0, 7.72) |

*a* 1-tail.

*b* dependent t-test, df 7.

**Abbreviations**: Activ_Red, activity reduction; CI, confidence interval; Corr Coeff, correlation coefficient; Neg_Emotion, negative emotion.

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**Table 1 Demographics**

| Variable | Control | Treatment |
|----------|---------|-----------|
| n (%)    | n (%)   |           |
| Total    | 6 (43)  | 8 (57)    |
| Male     | 6 (100) | 7 (88)    |

| Variable | Mean (SD) | Mean (SD) |
|----------|-----------|-----------|
| Age (y)  | 44.8 (7.4)| 44.5 (6.6)|
Interventions such as diaphragmatic breathing, progressive muscle relaxation, and guided imagery are standard treatments in cognitive-behavioral approaches to chronic pain. These protocols work to help the patient achieve relaxation even while experiencing pain. Through this relaxation, the efferent parasympathetic outflow is increased and heart rate is reduced. This increase in efferent activity is also accomplished with HRVBC; however, an additional mechanism that has been shown to inhibit pain pathways is also activated when participants are in a coherent state. The vagus nerve is a major conduit though which afferent cardiovascular signals are relayed to the brain. Lehrer has shown that by using HRVBC, a lasting increase in baroreflex gain is accomplished independent of respiratory and cardiovascular changes, thus demonstrating neuroplasticity of the baroreflex system. This shift in baroreflex gain indicates that with as few as six episodes of coherence training, the activation threshold of some of the mechanosensory neurons in the baroreflex

![Figure 1: Measures pre-post (control vs treatment). Abbreviations: BPI, Brief Pain Inventory; HRV, heart rate variability.](image-url)
system is reset, and as a result, these neurons increase their output accordingly. A basic property of cardiac afferent mechanosensory neurons is that they increase their output in response to an increase in the variability in either heart rate or blood pressure. During HRVC, there is an increase in beat-to-beat variability in both heart rate and blood pressure, which is equivalent to an increase in the rate of change. This results in an increase in the vagal afferent traffic sent from the heart and cardiovascular system to the brain. It has been established that an increase in the normal intrinsic levels of vagal afferent traffic inhibits the pain pathways traveling from the body to the thalamus at the level of the spinal cord, and a recent study has found that stimulation of the afferent vagal pathways significantly reduces cluster and migraine headaches. Several mechanisms have been identified that explain how increased vagal afferent activity decreases pain sensitivity and increases pain threshold. Nociceptive information (pain signals) from the skin and internal organs is carried to cell bodies located in the dorsal root ganglia of the spinal cord.

Axons from neurons in the dorsal root ganglia penetrate the spinal cord and convey afferent pain information to localized regions of the gray matter in the cord. From there, afferent information ascends in pathways to both the lateral and medial thalamus. Cells of the lateral thalamus in turn project to the primary somatosensory cortex, where the location, intensity, and duration of the painful stimulus are analyzed. Information is sent from the medial thalamus to the insular cortex, amygdala, and cingulate gyrus, where motivational-affective components of pain, including autonomic adjustments, occur. This pathway is called the spinothalamic tract (STT) and, although not the only pain pathway, it is the main and most studied pathway that transmits visceral sympathetic afferent pain information to the brain. Afferent fibers in the vagus nerve participate in the modulation of pain partly by modulating the flow of pain signals in the STT. An increase in afferent vagal activity causes a general inhibitory effect at most levels of the spinal cord on neurons that transmit nociceptive information to the thalamus and then to areas of the brain involved in pain perception. Vagal afferent fibers terminate primarily in the caudal medulla of the brainstem and nucleus tractus solitarius (NTS), and evidence shows that suppression of spinal neuronal activity is dependent upon the NTS connections. It has been demonstrated that the cardiac branch of the vagus nerve makes up the major contribution for the inhibitory responses on the spinal pain signals and that left vagal stimulation suppresses approximately 60% of the STT cells. Thus, the predominant effect of increased vagal afferent activity, which is associated with increased coherence, is the suppression of somatic and visceral input to STT cells, which provides a mechanism for decreasing pain.

Thus, these two forms of treatment, cognitive behavioral therapy and HRVCB, work in harmony toward the common goals of emotional and ANS regulation associated with enhanced efferent and afferent vagal activity.

Limitations

The present study is exploratory, and further research is needed to examine the efficacy of HRVCB in the amelioration of pain symptoms in veterans suffering from chronic pain. The primary purpose of the study was to lay the groundwork for a more complete research study in the future and collect preliminary data to be used in proposal applications for larger-scale grant funding. This pilot study was designed simply to test the feasibility of implementing the HRV biofeedback therapy in our hospital setting.

Major limitations of this study include small group sizes of a convenience sample and the short intervention period. The number of participants and length of intervention were so limited because the availability of resources of research personnel time commitment and funding was low. Because of the small sample sizes, the number of diagnoses and pain conditions included was limited, producing a significant limitation to the generalizability of the findings.

Furthermore, while the outcome variables were carefully selected, another limitation in the study is that only a minimal battery of tests was used. The demographic description of the sample was limited to age and sex, and other important demographic data and covariates were not used in the analysis (eg, cause of pain, chronicity, location, severity; medications). Additional outcomes measured such as sleep, quality of life, activity, and task performance were not assessed.

The two group pre-post study design allowed us to report that HRVCB therapy increased coherence and at the same time decreased subjective pain and stress ratings relative to a treatment as usual. Yet the causal inference that improved pain and stress ratings were a result of the increased HRV coherence is weak. A large-scale, randomized clinical trial testing HRVCB against both treatment as usual and sham treatment to control for environmental effects of the lab visits is necessary to have (1) broader generalizability to pain diagnoses and
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conditions and (2) stronger causal attributions of the effects of HRVCB to improved outcomes, including pain and stress ratings, quality of life, activity, and task performance. Clearly, more work is needed and must be done in this regard in the future.

Additional studies that attempt to replicate these findings are needed. A randomized, sham-treatment controlled and non-inferiority (to treatment as usual) clinical trial would provide stronger causal inference. A study design with sufficient sample size to stratify by age and gender would advance this work. Further research should explore factors related to more precisely measured as well as a broader array of autonomic function in chronic pain and the effects of HRVCB treatment on these factors. Lastly, the effects of HRVCB treatment on pain can and should be further advanced by examining within the same framework how symptoms and indicators of important adjuncts such as depression, anxiety, sleep disturbance, quality of life, and PTSD respond to the intervention.

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