PILOT STUDY

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*

Author Affiliations
Wm. Jennings Bryan Dorn VA Medical Center, Columbia, South Carolina.

Correspondence
Jay P. Ginsberg, PhD
Jay.Ginsberg@va.gov

Citation
Global Adv Health Med. 2014;3(2):28-33. DOI: 10.7453/gahmj.2013.075

Key Words
Coherence, heart rate variability (HRV), HRV coherence biofeedback (HRVCB); chronic pain, non-pharmacological intervention

Disclosure
The authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest and had no conflicts to disclose.

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 treatment and control groups at baseline on any of the measures. Post-HRVCB, the treatment group was significantly higher on coherence (P=.01) and lower (P=.02) on pain ratings than the control group. The treatment group showed marked and statistically significant (1-tailed) increases over the baseline in coherence ratio (191%, P=.04) and marked, significant (1-tailed) reduction in pain ratings (36%, P<.001), 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-regulation[8] 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 HRV[10] and inhibition of pain pathways in the spinal column.[11] Recent research using particular self-regulation techniques has shown significant increases in HRV coherence and associated reductions in symptoms of a variety of disorders, such as chronic pain,[12-15] anxiety,[16-18] depression,[19,20] insomnia,[21] asthma[22-25] 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 of 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 a pain-free state and 10 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.[28] 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.
5. 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

Table 1 Demographics

	Control	Treatment
	n (%)	n (%)
Total	6 (43)	8 (57)
Male	6 (100)	7 (88)
	Mean (SD)	**Mean (SD)**
Age (y)	44.8 (7.4)	44.5 (6.6)

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).

Table 2 Pre- and Post-training Measures for Both Groups, Mean (SD)

Variable	Control	Treatment	*t*-value[a]	*P*[b]	95% CI of difference
Coherence_Pre	0.12 (0.07)	0.22 (0.19)	–1.2	.24	(–0.3, 0.8)
Coherence_Post	0.15 (0.09)	0.42 (0.24)	–2.6	.02	(–0.5, –0.1)
Pain_Pre	26.2 (4.2)	27.1 (4.9)	–0.4	.70	(–6.4, 4.5)
Pain_Post	24.3 (6.9)	17.3 (4.6)	2.3	.04	(0.4, 13.8)
Stress_Pre	24.8 (6.8)	24.4 (5.8)	0.1	.90	(–6.8, 7.8)
Stress_Post	26.0 (6.9)	20.4 (6.1)	1.6	.14	(–1.9, 13.2)
Neg_Emotion_Pre	30.2 (9.7)	35.0 (3.5)	–1.2	.28	(–15.0, 5.3)
Neg_Emotion_Post	25.7 (12.7)	19.8 (10.4)	1.0	.36	(–7.5, 19.4)
Activ_Red_Pre	30.7 (7.1)	34.1 (4.6)	–1.1	.30	(–10.2, 3.3)
Activ_Red_Post	26.7 (11.6)	19.9 (10.4)	1.2	.26	(–6.1, 19.7)

[a] independent t-test, 12 df, all variances equal except Neg_Emotion_Pre.
[b] 2-tail.
Abbreviations: Activ_Red, activity reduction; CI, confidence interval; Neg_Emotion, negative emotion.

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%, *P*<.001), stress (16%, *P*=.02), negative emotion (49%, *P*<.001), and limitation of physical activity (42%, *P*<.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* values <.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.

Table 3 Pre-Post Changes of Measures in the Active HRVCB Treatment Group, Mean (SD)

Variable	Pre	Post	% Change	Corr_Coeff (*P*[a])	t-value[b]	*P*[a]	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.

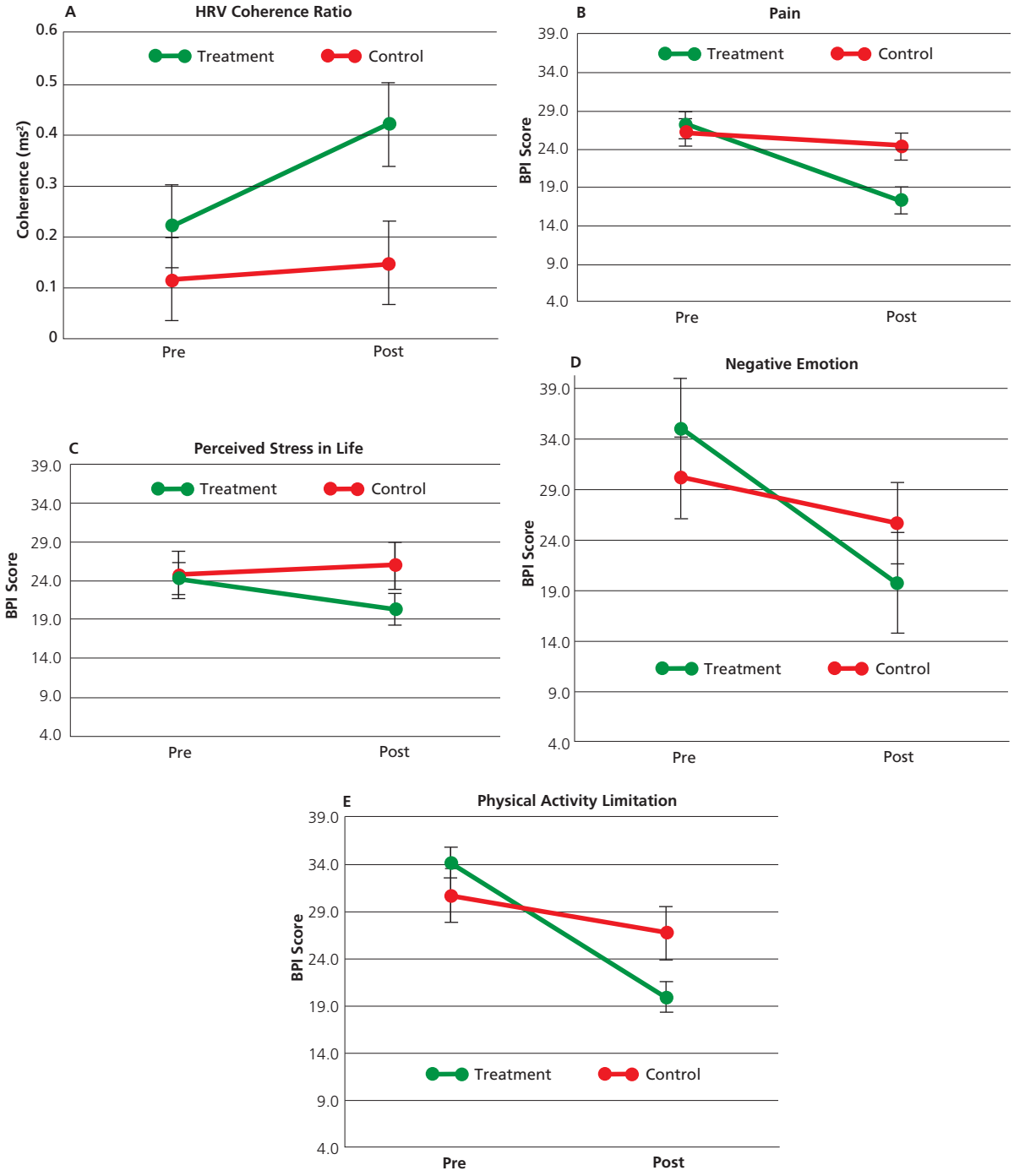

Figure 1 Measures pre-post (control vs treatment).
Abbreviations: BPI, Brief Pain Inventory; HRV, heart rate variability.

Interventions such as diaphragmatic breathing, progressive muscle relaxation, and guided imagery are standard treatments in cognitive-behavioral approaches to chronic pain.[40] 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 HRVCB, a lasting increase in baroreflex gain is accomplished independent of respiratory and cardiovascular changes, thus demonstrating neuroplasticity of the baroreflex system.[41] 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

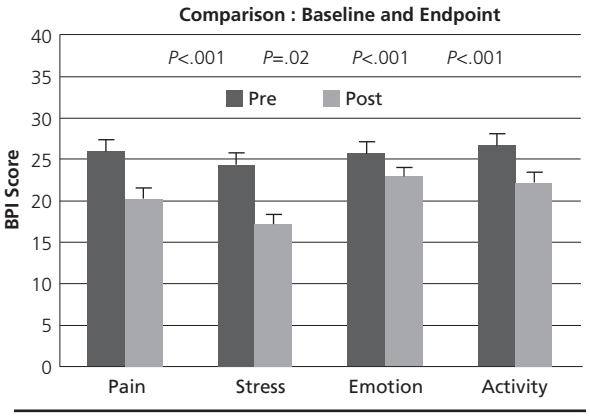

Figure 2 Heart rate variability coherence biofeedback (HRVCB) treatment group pre-post.

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.[42] 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.[6] 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.[43] 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 system that transmits visceral sympathetic afferent pain information to the brain.[44] 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.[11,45]

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

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.

Acknowledgments

We would like to thank the veterans at the Wm. Jennings Bryan Dorn VA Medical Center Pain Clinic for their willingness to assist us with our research. We gratefully acknowledge the primary care clinicians who participated in this study and the Dorn Research Institute staff. This research project was supported by the Dorn Research Institute, Dorn VA Medical Center, Columbia, South Carolina.

REFERENCES

1. Benyamin R, Trescot AM, Datta S, et al. Opioid complications and side effects. Pain Physician. 2008;11 (2 Suppl): S105-20.
2. Seal KH, Shi Y, Cohen G, et al. Association of mental health disorders with prescription opioids and high-risk opioid use in US veterans of Iraq and Afghanistan. JAMA. 2012;307(9):940-7.
3. Logier R, Jeanne M, Tavernier B, De Jonckheere J. Pain/analgesia evaluation using heart rate variability analysis. Conf Proc IEEE Eng Med Biol Soc. 2006.1:4303-6.
4. Mostoufi SM, Afari N, Ahumada, Reis V, Wetherell JL. Health and distress predictors of heart rate variability in fibromyalgia and other forms of chronic pain. J Psychosom Res. 2012;72 (1):39-44.
5. Appelhans B, Luecken L. Heart rate variability as an index of regulated emotional responding. Review of General Psychology. 2006;10(3):229-40.
6. McCraty R, Atkinson M, Tomasino D, Bradley RT. The coherent heart: heart-brain interactions, psychophysiological coherence, and the emergence of system-wide order. Integral Review. 2009;5(2):10-115.
7. Pumprla J, Howorka K, Groves D, Chester M, Nolan J. Functional assessment of heart rate variability: physiological basis and practical applications. Int J Cardiol. 2002;84(1):1-14.
8. Thayer JF, Hansen AL, Saus-Rose E, Johnsen BH. Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. Ann Behav Med. 2009;37(2):141-53.
9. Friedman BH. An autonomic flexibility-neurovisceral integration model of anxiety and cardiac vagal tone. Biol Psychol. 2007;74(2):185-99.
10. Mackinnon S, Gevirtz R, McCraty R, Brown M. Utilizing heartbeat evoked Potentials to Identify Cardiac Regulation of Vagal Afferents During Emotion and resonant breathing. Appl Psychophysiol Biofeedback. 2013;38(4):241-55. doi: 10.1007/s10484-013-9226-5
11. Foreman RD. Vagal afferent modulation of cardiac pain. In Vagal control of the heart: experimental basis and clinical implications. Levey MN, Schwartz PJ, editors. Futura Publishing Co: Armonk, New York. 1994:345-68.
12. Hassett AL, Radvanski DC, Vaschillo EG, et al. A pilot study of the efficacy of heart rate variability (HRV) biofeedback in patients with fibromyalgia. Appl Psychophysiol Biofeedback. 2007;32(1):1-10.
13. Appelhans BM, Luecken LJ. Heart rate variability and pain: associations of two interrelated homeostatic processes. Biol Psychol. 2008;77(2):174-82.
14. Paine P, Kishor J, Worthen SF, Gregory LJ, Aziz Q. Exploring relationships for visceral and somatic pain with autonomic control and personality. Pain. 2009;144(3):236-44.
15. Kapitza KP, Passie T, Bernateck M, Karst M. First non-contingent respiratory biofeedback placebo versus contingent biofeedback in patients with chronic low back pain: a randomized, controlled, double-blind trial. Appl Psychophysiol Biofeedback. 2010;35(3):207-17.
16. Reiner R. Integrating a portable biofeedback device into clinical practice for patients with anxiety disorders: results of a pilot study. Appl Psychophysiol Biofeedback. 2008;33(1):55-61.
17. Henriques G, Keffer S, Abrahamson C, Horst SJ. Exploring the effectiveness of a computer-based heart rate variability biofeedback program in reducing anxiety in college students. Appl Psychophysiol Biofeedback. 2011;36(2):101-12.
18. Hallman DM, Olsson EM, von Scheele B, Melin L, Lyskov E. Effects of heart rate variability biofeedback in subjects with stress-related chronic neck pain: a pilot study. Appl Psychophysiol Biofeedback. 2011;36(2):71-80.
19. Karavidas MK, Lehrer PM, Vaschillo E, et al. Preliminary results of an open label study of heart rate variability biofeedback for the treatment of major depression. Appl Psychophysiol Biofeedback. 2007;32(1):19-30.
20. Siepmann M, Aykac V, Unterdorfer J, Petrowski K, Mueck-Weymann M. A pilot study on the effects of heart rate variability biofeedback in patients with depression and in healthy subjects. Appl Psychophysiol Biofeedback. 2008;33(4):195-201.
21. McLay RN, Spira JL. Use of a portable biofeedback device to improve insomnia in a combat zone, a case report. Appl Psychophysiol Biofeedback. 2009;34(4):319-21.
22. Lehrer P, Smetankin A, Potapova T. Respiratory sinus arrhythmia biofeedback therapy for asthma: A report of 20 unmedicated pediatric cases using the Smetankin method. Applied Psychophysiology and Biofeedback. 2000;25(3):193-200.
23. Lehrer PM, Vacschillo E, Vaschillo B, et al. Biofeedback treatment for asthma. Chest. 2004;126(2):352-61.
24. Lehrer P, Vaschillo E, Lu SE, et al. Heart rate variability biofeedback: effects of age on heart rate variability, baroreflex gain, and asthma. Chest. 2006;129(2):278-84.
25. Ritz T, Dahme B, Roth WT. Behavioral interventions in asthma: biofeedback techniques. J Psychosom Res. 2004;56(6):711-20.
26. Nolan RP, Kamath MV, Floras JS, et al. Heart rate variability biofeedback as a behavioral neurocardiac intervention to enhance vagal heart rate control. Am Heart J. 2005;149(6):1137.
27. Swanson KS, Gevirtz RN, Brown M, Spira J, Guarneri E, Stoletniy L. The effect of biofeedback on function in patients with heart failure. Appl Psychophysiol Biofeedback. 2009;34(2):71-91.
28. Ginsberg JP, Berry ME, Powell DA. Cardiac coherence and PTSD in combat veterans. Alternative Therapies in Health and Medicine. 2010;16(4):52-60.
29. Vanderbilt D, Young R, MacDonald HZ, Grant-Knight W, Saxe G, Zuckerman B. Asthma severity and PTSD symptoms among inner city children: a pilot study. J Trauma Dissociation. 2008;9(2):191-207.
30. Zucker TL, Samuelson KW, Muench F, Greenberg MA, Gevirtz RN. The effects of respiratory sinus arrhythmia biofeedback on heart rate variability and posttraumatic stress disorder symptoms: a pilot study. Appl Psychophysiol Biofeedback. 2009;34(2):135-43.
31. Cleeland CS, Ryan KM. Pain assessment: global use of the brief pain inventory. Ann Acad Med Singapore. 1994;23(2):129-38.
32. Serlin RC, Mendoza TR, Nakamura Y, Edwards KR, Cleeland CS. When is cancer pain mild, moderate or severe? grading pain severity by its interference with function. Pain. 1995;610(2):277-84.
33. Gauthier LR, Rodin G, Zimmermann C, et al. Acceptance of pain: a study in patients with advanced cancer. Pain. 2009;143(1-2):147-54.
34. Darnall B, Elizabeth S. Characteristics and pain catastrophizing in incarcerated women with chronic pain. J Health Care Poor Underserved. 2012;23:543-556.
35. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. J Health Soc Behav. 1983;24(4):385-96.
36. Cleeland CS, Nakamura Y, Mendoza TR, Edwards KR, Gouglas J, Serlin RC. Dimensions of the impact of cancer pain in a four country sample: new information from multidimensional scaling. Pain. 1996;67(2-3):267-73.
37. Asmundson GJ, Norton PJ, Norton GR. Beyond pain: the role of fear and avoidance in chronicity. Clin Psychol Rev. 1999;19(1):97-119.
38. Sephton SE, Salmon P, Weissbecker I, et al. Mindfulness meditation alleviates depressive symptoms in women with fibromyalgia: results of a randomized clinical trial. Arthritis Rheum. 2007;57(1):77-85.
39. Cioffi D, Holloway J. Delayed costs of suppressed pain. J Pers Soc Psychol. 1993;64(2):274-82.
40. Otis J. Managing chronic pain: a cognitive behavioral therapy approach. New York, NY: Oxford University Press, Inc; 2007.
41. Lehrer PM, Vaschillo E, Vaschillo B, et al. Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. Psychosomatic Medicine. 2003;65(5):796-805.
42. Armour JA, Kember GC. Cardiac sensory neurons, in basic and clinical neurocardiology. Armour JA, Ardell JL, editors. Oxford University Press: New York; 2004:79-117.
43. Mauskop A. Vagus nerve stimulation relieves chronic refractory migraine and cluster headaches. Cephalalgia. 2005;25(2):82-6.
44. Foreman RD. Organization of the spinothalamic tract as a relay for cardiopulmonary sympathetic afferent fiber activity. Progress in Sensory Physiology. 1989;9:1-51.
45. Foreman R. Organization of visceral input, in anesthesia: biologic foundations. Lippincott-Raven Publishers: Philadelphia; 1997:663-83.