Activitas Nervosa Superior Rediviva Volume 63 No. 3 2021

ORIGINAL ARTICLE

HRV biofeedback and controlled slow breathing may have limited effectiveness as stress reduction methods in healthy subjects

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Submitted: 2021-05-13 *Accepted: 2021-06-02* *Published online: 2021-11-12*

Key words: **Heart rate variability; Biofeedback; Breathing; Training; Stress**

Act Nerv Super Rediviva 2021; **63**(3): 111–117 ANSR63321A03

Abstract

BACKGROUND: In recent years, heart rate variability (HRV) biofeedback has become increasingly popular for its proven success in stress management. The aim of the presented study was to compare the effect of the HRV biofeedback and controlled slow breathing on the parameters of HRV and perceived stress.
METHODS: Seventy-five healthy young adults were randomly assigned to one of three groups: HRV biofeedback, controlled breathing, and no-treatment control. All subjects were given pre- and post-intervention assessment sessions which included relax and stress condition. Physiological data were collected and analyzed separately at relax and stress. Subjects assigned to biofeedback and controlled breathing treatments underwent ten 10-minutes sessions of training over 10 weeks.
RESULTS: Data analysis did not show a significant effect of HRV biofeedback and controlled breathing on HRV parameters and perceived stress and no significant differences were found between groups.
CONCLUSION: Results from presented study suggest that the emWave and controlled slow breathing may have limited effectiveness as stress reduction methods in healthy subjects. Future research of the HRV biofeedback treatment protocol which defines indications, conditions, number of sessions or process of its use is necessary before it can be recommended for regular use in clinical practice and at-home use.

Introduction

A characteristic feature of modern society is the constant stress exposure that often leads to chronic responses to stress. From an evolutionary point of view, we are well-equipped with reactivity to acute stress but stress which persists over an extended period of time has a negative impact on the physical and mental health of the individual (McEwen & Wingfield 2003). Consequently, it has been suggested that interventions aimed at effectively managing stress and eliminating its negative consequences may prove beneficial for treating a broad range of stress-related conditions (de Bruin *et al.* 2016).

One method that has shown some promise in treating various mental and somatic conditions is biofeedback. Biofeedback is a self-regulation technique which enables the individual to learn how to change psychophysiological activity potentially improving health and performance. It provides feedback information about physiological function in comprehensible and graphically attractive form, assisting the individual to gain conscious control over these processes (Schwartz & Andrasik 2003). Biofeedback came into clinics or private practices relatively quickly, even though there is no available universal and integrated manual or protocol which defines indications, conditions or process of its use. Intensive research in this area could bring required findings and knowledge that can be used for this purpose.

There are several types of biofeedback depending on the used signal. Heart rate variability (HRV) describes the oscillations in the beat-to-beat interval (Wheat & Larkin 2010). Since heart rate fluctuations are controlled by ANS, HRV provides non-invasive and easily applied method to evaluate the autonomic nervous system's (ANS) function and the sympatho-vagal interactions. While higher HRV is associated with good adaptation, resilience and self-regulatory strength, reduced HRV is indicator of an abnormal regulation of ANS and higher risk of cardiovascular diseases (Task Force 1996; Quintana & Heathers 2014).

HRV biofeedback is a technique for increasing HRV and achieving ANS balance that has shown some promise in treating various physical and mental health conditions including depression (Siepmann *et al.* 2008; Zucker *et al.* 2009), anxiety and stress-related disorders (Goessl *et al.* 2017; McCraty *et al.* 2009; Nolan *et al.* 2005; Zucker *et al.* 2009), hypertension (Lin *et al.* 2012; McCraty *et al.* 2009; Nolan *et al.* 2005), asthma (Lehrer *et al.* 2000; Lehrer *et al.* 2004) and heart disease (Nolan *et al.* 2005). The purpose of this method is self-regulation which refers to the ability of an individual to control psychophysiological states based on autonomic and central nervous system functioning (Prinzel *et al.* 2001). HRV is measured through electrocardiogram (ECG) or photoplethysmography (PPG) and is displayed in graphically attractive and understandable form in real time (Lehrer 2007). The basic principle of HRV biofeedback is to breathe at a specific individual rate called resonance frequency (Vaschillo *et al.* 2006). A number of HRV biofeedback studies have demonstrated that the HRV biofeedback training practiced with paced breathing at a rate 0.1 Hz (6 breaths/min) has clinical utility for the treatments of physical and mental disorders which involve ANS dysregulation (Lehrer *et al.* 2004; McCraty *et al.* 2003; Lehrer *et al.* 2003; Lehrer & Gevirtz 2014). Rhythmically stimulation of the cardiovascular system by paced breathing at a frequency of 0.1 Hz leads to maximal increases in the amplitude of HRV. This phenomenon is connected with respiratory sinus arrhythmia and resonance properties of the cardiovascular system resulting from activity of the baroreflex (Vaschillo *et al.* 2002; 2006). However, simply telling people to breathe at 6 breaths/min is not sufficient. Rate of maximum amplitude fluctuation may change over time during training and individuals' optimal breathing rate (i.e. their resonance frequency) for producing large increases in HRV and baroreflex gain varies mildly from person to person depending on individual differences in physiology and factors like height or gender. Thus biofeedback

Tab. 1. Within-subject effects in HRV parameters and their interactions

	Before		After		stage F	condition F	stage x condition F
	Relax Mean ± SD	Stress Mean ± SD	Relax Mean ± SD	Stress Mean ± SD			
HR	84,33 ± 10,17	94,61 ± 11,57	84,83 ± 10,13	91,73 ± 9,79	1,540	87,126**	19,704**
mean RR	725,74 ± 90,75	646,99 ± 80,23	722,83 ± 94,62	665,47 ± 76,67	1,003	86,168**	12,764**
SDNN	50,97 ± 16,25	44,51 ± 18,10	55,42 ± 25,64	45,94 ± 21,08	2,593	23,604**	1,655
RMSSD	33,03 ± 15,36	24,68 ± 13,61	33,91 ± 19,05	26,10 ± 14,90	,632	37,690**	,160
Total p.	3,32 ± 0,30	3,16 ± 0,36	3,34 ± 0,41	3,18 ± 0,45	,195	22,672**	,004
VLF	2,83 ± 0,38	2,73 ± 0,36	2,79 ± 0,42	2,74 ± 0,50	,052	3,158	,778
LF	2,89 ± 0,33	2,76 ± 0,41	2,94 ± 0,47	2,78 ± 0,42	1,048	14,626**	,267
HF	2,60 ± 0,44	2,33 ± 0,53	2,53 ± 0,53	2,34 ± 0,52	,457	32,221**	3,418
LF/HF	2,69 ± 2,36	3,60 ± 3,46	4,40 ± 6,44	3,34 ± 2,08	1,194	9,202**	5,613*
SD1	23,39 ± 10,56	17,47 ± 9,63	24,01 ± 13,49	18,48 ± 10,54	,634	37,742**	,172
SD2	67,85 ± 21,36	60,20 ± 24,30	74,31 ± 34,31	62,08 ± 28,17	2,983	19,720**	1,951

Abbreviations: SD - standard deviation, HR – heart rate, mean RR – mean RR interval, SDNN - standard deviation of the normal to normal interval, RMSSD - square root of the mean squared differences of successive normal to normal intervals, LF - low frequency, HF - high frequency, LF/HF - ratio of LF to HF, SD1 - standard deviation of the instantaneous RR variability, SD2 - standard deviation of the continuous or long term variability of the heart rate.
* $p = 0.05$ ** $p = 0.01$

technique is required to determine the precise rate of breathing required for each individual in real time (Eddie *et al.* 2015).

The emWave (formerly the Freeze Framer, HeartMath Institute, Boulder, CO) is HRV biofeedback that is widely available to the public for purchase on the website and focus on changing negative affect to positive with the aid of paced breathing (Henriques *et al.* 2011). This device has potential to be used by professionals in clinics or private practices and also for personal use at home. While traditional HRV biofeedback studies emphasize breathing at the resonance frequency at which maximum amplitudes of HRV could be generated voluntarily for each individual, creators at the HeartMath Institute treatment declared that the emWave focuses on the induction of positive emotional states that are associated with "psychophysiological coherence" (McCraty & Tomasino 2006). These biofeedback methods differ and it is unclear whether effectiveness of their use is comparable. There are very few studies focused on effectiveness of emWave and no study has been conducted to validate the emWave as a tool for improving HRV. In our previous pilot study (Solarikova *et al.* 2016) we did not observe any effect of emWave on HRV and psychological distress, but subjects practiced training at home. Therefore, in current study subjects received training in a laboratory with the aim of securing better control over training. The purpose of the present study was to compare effect of the emWave treatment and controlled breathing on HRV parameters and perceived stress. Deep, slow or controlled breathing seems to be also helpful in the management of acute stressful tasks (Nogawa *et al.* 2007) and influencing of autonomic functions (Mourya *et al.* 2009; Ursino & Magosso 2003) but there are also contradictory reports (Logtenberg *et al.* 2007). This may be partly because physiologic feedback is absent in controlled breathing and the subject cannot make accurate adjustments based on visualized physiologic feedback (Wang *et al.* 2010). Therefore, our goal was also to study whether simply controlled breathing without feedback could be effective way of increase in HRV and decrease in perceived stress.

Methods

<u>Subjects</u>

75 healthy volunteers (women n = 60, men n = 15; mean age 21 years; range 19-36 years), university students, participated in our research. Each student received course credit for participation. None of the subjects reported cardiovascular or neurological problems, or any kind of treatment that would interfere with cardiovascular and autonomic functions. Subjects were randomly divided into 3 groups: biofeedback treatment (n = 26), breathing training (n = 24), and no treatment control group (n = 25). All subjects attended pre- and post-intervention assessment sessions during which relax video and acute stressors were administered. They signed an informed consent to participate to the research.

<u>Procedure</u>

Self-Report Instruments

Perceived Stress Scale (PSS) (Cohen *et al.* 1983) was used to evaluate subjects' level of perceived stress in the past month. The PSS is a 10-item self-report scale with 5-point scale (0 = never, 4 = very often) that measures perceptions of life stress, including how often subjects perceived their life to be uncontrollable, unpredictable, and overwhelming. This scale is widely used in stress research and has demonstrated normative data and reliability.

Pre- and post-intervention assessment

All subjects completed pre-intervention and post-intervention assessment in group setting, during which we monitored their HRV and perceived stress in sitting position. Wheat & Larkin (2010) point out that it is important to control factors such as alcohol, nicotine, caffeine and intensive exercise, which directly correlate with autonomic activity. Therefore, subjects were asked to abstain from caffeine containing foods and beverages least four hours before the assessment. After informed consent was obtained from them, they completed the PSS. Tendency of researchers to verify the effect of HRV biofeedback only at rest is considered to be one of the most significant limits of research with HRV biofeedback (Whited *et al.* 2014). Therefore we administered both relax and stress protocols during which ECG measures were collected by ECG portable FAROS 90°. We used two 5-minute sections in the HRV analysis. The first one comes from the relax session and the second one comes from stress protocol. *Relax:* In this interval subjects rested in a comfortable chair for 6 minutes and watched relaxing video with calming music and sounds. *Stress:* The stress protocol involved a combination of several stress stimuli with the aim of reliably inducing psychophysiological changes relevant to stress experience. In the first part the subjects were asked to memorize the story (A) from subtest Logical Memory I of WMS-III during 2 minutes. After that they were instructed to solve mental arithmetic task in written form in the presence of alarm sounds of siren. During this sound, acoustic stimuli appeared in random intervals, which changed the instruction for arithmetic task. The mental arithmetic task part was lasting for 6 minutes. Then the subjects were required to remember the key concepts of the story from the memory task and fill it in the blanks. Post-intervention measures design was the same but with the aim of avoiding habituation to repeatedly presented stressors, we used an alternative story (B) from WMS-III and changed numbers and intervals of the acoustic stimuli in mental arithmetic task.

Treatment protocols

Subjects assigned to biofeedback and breathing pacer treatments underwent 10 sessions of training over 10 weeks.

Biofeedback Group: Subjects attended introductory training instruction, which includes information about HRV, basic principles and mechanisms of HRV biofeedback, health benefits of use of it and also demonstration of software and HRV biofeedback device emWave. After the introductory meeting, subjects practiced 10 HRV biofeedback sessions for 10 minutes every week. Each individual training session was led by the investigator at laboratory room. HRV sensor was connected to participants' ear lobe with purpose to measure their heart rate (HR), from which was calculated HRV coherence that was display on a desktop computer in real time. The form of training (The coherence coach/games/visualizers) was regularly changed to avoid a monotony and tediousness of whole training. The initial sessions were mainly focused on acquiring the proper breathing patterns using The Coherence Coach animation. In the next sessions the subjects were practiced by way of various animations or games (for example, a balloon game in which speed of balloon depends on HRV values).

Breathing Group: In this group, subjects received ten 10-minute controlled breathing sessions for 10 weeks, therefore the range and duration were in accordance with HRV biofeedback training. Subjects performed controlled breathing while watching a computer animation teaching them how to breathe at the rate of 6 breaths/min. Slow and deep breathing is considered to be one of the physiological ways of HRV increasing and the rate of 6 breaths/min leads to a maximal increase in the HR oscillation amplitude (Ursino & Magosso 2003; Vaschillo *et al.* 2006). The principal aspect of this treatment protocol was the absence of feedback, which is the basis of biofeedback and its effect is supported by the principles of operant conditioning.

HR data for each condition (relax and stress) of pre- and post-intervention assessment sessions (stages) were imported to Kubios HRV Analysis Software v2.0 (Biosignal Analysis and Medical Imaging Group, Kuopio, Finland) for preparation and analysis of HRV. Within the Kubios program, R–R interval data were visually checked for missing or erroneous data and low-level artifact correction was employed in these cases. We focused on these selected parameters of HRV: HR, SDNN, RMSSD, total power, VLF, LF, HF, LF/HF, SD1 and SD2. They were recorded during two conditions (relax and stress) both before and after intervention. Spectral HRV parameters (LF, HF, VLF and total power) were logarithmically transformed to correct for skewness. The statistical analyses were performed using the IBM SPSS Statistics version 23.0 for Windows by means of a 2 × 2 ANOVA with group as a between-subject factor. Within-subjects factors were stage (pre- and post-intervention treatment) and condition (relax and stress).

Results

When all subjects were assessed (n = 75), there was no effect of test stages (pre- and post-intervention) on any HRV parameters which means that none of the treatment protocol affected HRV. Difference between conditions (relax and stress) was significant for SDNN, RMSSD, total power, LF, HF, SD1 and SD2 (Table 1). The resulting mean values of these HRV parameters are lower in stress condition than in relax. A decrease in mentioned HRV parameters is related to stress experience (Taelman *et al.* 2009; Berntson & Cacioppo 2004; Brosschot *et al.* 2007), therefore the overall reduction in HRV indicate that the laboratory stress condition leads to physiological changes relevant to stress experience. Significant stage x condition interaction was evident for HR and LF/HF (Table 1). There was found decrease in HR (F = 87,126; p = 0,000) during stress in post-intervention stage and increase in LF/HF (F = 9,202; p = 0,003) during relax in post-intervention stage. No significant interactions were observed for SDNN, RMSSD, total power, LF, HF, SD1 and SD2. However, all the above-mentioned significant effects were found regardless of group and since no main differences were found between groups (F = 0,899 p = 0,596), no further post hoc testing was carried out.

Self-Report Outcomes

Repeated-measures ANOVA was conducted to compare PSS score across pre- and post-intervention stages with Dunnett's post-hoc test. Changes in the total PSS score between pre- and post-intervention stages have not significant value (F = 0,712 p = 0,402) and there were not significant differences between groups in PPS score.

Discussion

The aim of this study was to examine the difference in the effect of commercially available HRV biofeedback and controlled slow breathing on post-training HRV parameters and subjectively perceived stress in healthy adult sample. We assessed HRV parameters and PSS score during two opposite conditions (relax and stress) at two different time points (pre- and post-intervention sessions). No significant differences in HRV or PSS score were observed between subjects who received biofeedback, controlled breathing and those who were maintained under control condition. These results do not support findings of the majority of previous studies where the time or frequency domain parameters of HRV were found increased after biofeedback treatment (Del Pozo *et al.* 2004; Lehrer *et al.* 2003; Lehrer & Gevirtz 2014). However, while the mentioned studies applied training protocol focused on breathing at the resonance frequency, biofeedback treatment protocol in current study was based on commercially available emWave manual which does not include learning to breathe at the resonance frequency. There are other studies that similar to us did not find or found only very limited effect of emWave biofeedback on HRV or perceived stress (Henriques *et al.* 2011; Whited *et al.* 2014). Furthermore, Lehrer *et al.* (2003) in their study with 54 healthy subjects observed that none of the biological changes in the biofeedback group were closely related to their own relaxation experiences and in conclusion suggest that cardiorespiratory effects cannot be explained by relaxation. Another study (Sherlin *et al.* 2009) found that HRV biofeedback focused on breathing at the resonance frequency is more effective in reducing state anxiety and HR than HRV biofeedback without the instruction to breathe at a specific rate. Overall, our findings support the importance of using explored and verified HRV biofeedback protocol which is commonly employed across many studies reviewed herein.

Moreover, HRV biofeedback may confer some limited treatment effects in healthy subjects. There are very few studies focused on HRV biofeedback training in healthy sample, so this research area is still unclear. Siepmann *et al.* (2008) compared the effect of HRV biofeedback between depressed and healthy subjects, and while noticing reduced anxiety, decreased HR and increased HRV in depressed patients, they found no significant effect of HRV biofeedback in healthy sample. Previously mentioned study of Lehrer *et al.* (2003) did not find any long-term differences in HRV between biofeedback and control group, authors found only increase in HRV during biofeedback sessions and the increase in baroreflex gain that is used as a measure of the autonomic response to a given change in blood pressure (Wehrwein & Joyner 2013), during and also shortly after biofeedback sessions. In general the problem of many studies evaluating the effect of HRV biofeedback is examination of short-term effects of HRV biofeedback treatment, whereas the evidence for long-term increase HRV is tenuous (Wheat & Larkin 2010). On the basis of the above, future research should probe the possibilities of using HRV biofeedback with focus on long-term effects.

In post-intervention stage there were observed following interaction stage x condition without between-group differences; decrease in HR during stress and increase in LF/HF during relax. These results show a mild habituation of subjects to the conditions of the laboratory protocol despite its modification during post-intervention stage. The control group is really necessary because its absence can cause false positive results. Many studies claim to support the efficacy and beneficial effects of biofeedback without using a control group (Reyes 2014; Hassett *et al.* 2007; Giardino *et al.* 2004) which complicates the detection of the real effects of this method (Raaijmakers *et al.* 2013; Wheat & Larkin 2010). Our results support the need for a control group in studies focused to verify the effect of interventions.

We reflect some limitations of this study: First, we suppose that the overall frequency and intensity of the training was not sufficient to demonstrate the effect of the method. While in our research subjects attended 10-minute training session once a week, in studies that supported positive effects of HRV biofeedback, subjects had been trained more often, e.g. three times a week (Siepmann *et al.* 2008) or even three times a day (Lemaire *et al.* 2011; Ratanasiripong *et al.* 2015). Secondly, the emWave is commercial device with different method and protocol of use in comparison to certificated biofeedback. Therefore, the effect of them could differ. Although creators of the emWave provided a manual offering some recommendation for treatment, no evidence-based information regarding implementation of the emWave treatment is available. Besides this, motivation of subjects may also be a problem. While clinical population or business leaders have high level of intrinsic motivation to reduce symptoms and manage stress, motivation of students is incomparably lower.

In conclusion, we suggest that the emWave and controlled slow breathing may have limited effectiveness as stress reduction methods in healthy subjects. These results point out the need to distinguish commercial and public available methods from certificated and professional devices. More evidence-based results focused on stress reduction methods are required before they will be in common usage.

Conclusion

Despite the apparent shift towards understanding the nature of the capacity limitation of VWM as a continuous resource guided by attentional selection, the debate and competition between various models is ongoing. The most recent re-conceptualisation by Schneegans *et al.* (2020) offers an intriguing novel framework with a unifying potential that provides new opportunities for further research. The sampling framework certainly has some limitations, which are yet to be explored in detail, but the approach has been gaining popularity in neuroscience as a neurobiologically plausible account of how Bayesian inference may be performed online in the brain as it is presented with new information (Radulescu *et al.* 2021). For VWM, the current knowledge thus seems to favour resource-based approaches that implement the characteristics which result in some sort of discretisation.

Acknowledgments

This paper was supported by following grants: APVV-17-0451, APVV-0496-12, VEGA 1/0757/19 and 1/0786/21. Compliance with ethical standards

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Public Significance Statement

Heart rate variability (HRV) biofeedback has become increasingly popular for its proven success in stress management. The aim of the presented study was to compare the effect of the HRV biofeedback and controlled slow breathing on the parameters of HRV and perceived stress. Results from presented study suggest that the emWave and controlled slow breathing may have limited effectiveness as stress reduction methods in healthy subjects.

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