Resonant Breathing Biofeedback Training for Stress Reduction Among Manufacturing Operators

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The aim of this study was to examine the effect of resonant breathing biofeedback training for reducing stress among manufacturing operators. Resonant breathing biofeedback works by teaching people to recognize their involuntary heart rate variability and to control patterns of this physiological response. Thirty-six female operators from an electronic manufacturing factory were randomly assigned as the experimental group (n = 19) and the control group (n = 17). The participants of the intervention received 5 weekly sessions of biofeedback training. Physiological stress profiles and self-perceived depression, anxiety, and stress scale (DASS) were assessed at pre- and post-intervention. Results indicated that depression, anxiety, and stress significantly decreased after the training in the experimental group; they were supported by a significant increase in physiological measures. Overall, these results support the potential application of resonant biofeedback training to reduce negative emotional symptoms among industrial workers.

stress   resonant breathing   biofeedback   operators

1. INTRODUCTION

Job stress is a major occupational health problem in most industrialized countries; the term refers to stress attributed to job factors. Researchers have well documented that job stress impairs attention, memory, and action and that extreme forms of stress, such as burnout, clinical anxiety, and depression are detrimental to performance [1, 2]. In the industrial setting, reduced effectiveness due to stress can lead to misjudgment costing many thousands of dollars in damage to equipment as well as to workers' health and lives [3]. Further-more, the cost of job stress to an organization is unquestionable; it includes absenteeism, lost productivity, increased compensation claims, and high health care expenses [4, 5].

As any other industrial workers, manufacturing operators are also vulnerable to these adverse effects of job stress [6, 7]. In this occupational setting, sources of stress may be either physical, such as high job demands, noise, and improper lighting, or psychological, such as low job control, boring job, lack of social support, and lack of autonomy [8]. In addition, manufacturing workers generally work hourly shifts or overtime to ensure continu-

ous production. This condition leads to a disrupted circadian rhythm, which highly impacts the quality of work, sleep, and social life, resulting in more stress [9, 10]. Considering these problems, it was necessary to implement a stress management intervention in this occupational setting.

Nevertheless, there are no studies that evaluate the effect of stress management on industrial operators, particularly in Malaysia. From the perspective of the management, stress management intervention for workers at operative level is still presumed valueless because it costs a lot and is time-consuming, and workers cannot spare the time to practice any coping skills [11]. Thus, it is not surprising that little research has been conducted to date with this population of workers, although Colligan, Smith, and Hurrel's research revealed that blue collar workers had one of the highest rates of incidence of stress-related mental disorders [12]. Research has demonstrated that individuals with little or no control over their job experience greater stress than those with a high degree of control [13]. On the other hand, the manufacturing industry is an important engine of economic growth in the Malaysian economy and one of the largest employers in Malaysia [14]. Considering all these reasons, there is a great need to develop an intervention tool to decrease stress-related risk to performance among manufacturing operators.

There has been a growing body of research on the positive effect of various stress management techniques on combating the effect of stress in the workplace. Hart proposed four main approaches to stress management: physiological, behavioral, psychological, and environmental [4]. The first three approaches are also recognized as individual-focused strategies that aim at increasing an individual's resource to cope with stressful situations [5, 15]. In workplace settings, individual strategies have become popular because they are usually inexpensive and can be established and evaluated in a short time. Moreover, they take into account the personalized nature of the stressor [15]. In a recent meta-analysis study, van der Klink, Blonk, Schene et al. reported that individual-focused job stress management interventions

were effective in reducing workers' stress-related complaints [5]. Of all approaches, the physiological approach is the most popular one; it is an internally focused method. It works towards reducing excessive physiological arousal. This approach consists of progressive muscle relaxation, biofeedback, relaxation response, autogenic training, relaxation imagery, and aerobic training. Therefore, the present study is an individual-physiological-focused intervention.

Most physiological approaches include breathing exercise as a central component [16]. Researchers have shown that stressed and tense people are better able to think clearly and show decreased levels of stress after learning a particular form of breathing exercise [16, 17]. In a clinical setting, various forms of breathing retraining have been found to be effective treatments and treatment adjuncts for anxiety disorders and other disorders of autonomic dysregulation [18, 19, 20, 21]. Breathing retraining aims to cope with fast, deep, and irregular breathing of anxious or stressed individuals.

One promising breathing exercise strategy is resonant frequency breathing. This kind breathing is most frequently found in persons in a relaxed mental state with a positive emotional tone, and engaged in smooth full diaphragmatic breathing at their resonant frequency breathing rate of ~5–7 breaths per minute (BPM) [22]. Respiration rate is important because breathing is an oscillator that drives the heart rhythm. Conrad, Müller, Doberenz, et al. demonstrated that giving simple and short instructions to alter breathing did not change levels of activation either in terms of self-report or physiology measures [17]. They also showed the opposite of a prior concept that direct voluntary manipulation of breathing was easy, effortless, and pleasant. Biofeedback is an effective way to learn a particular breathing skill. This technique uses a person's physiological indicators based on the autonomic and central nervous systems and provides feedback so that the person learns to control these indicators and modulate their occurrence into a physiologically optimal state [23]. Feedback is either audio or visual. This form of feedback is particularly helpful for incorporating the mind–body connection into a train-

ing program, providing real evidence for clients that what they think and how they feel is integrally connected [24]. As people become more aware of their physiology, they can control it better. Biofeedback along with breathing exercise has been proved successful in the treatment and prevention of many stress-related problems [18, 19, 21]. Vaschillo, Vaschillo, and Lehrer also suggested that it was not enough just to tell people to breathe at their specific frequency because the exact cardiac resonant frequency differed from person to person [25]. Hence, biofeedback was also necessary to find the exact rate of breathing required for each individual.

In psychophysiology literature, resonant frequency breathing is one of the most popular heart rate variability (HRV) biofeedback techniques [20]. HRV is defined as the beat-to-beat changes in the interbeat interval (time between two successive R waves) [26]. The beat-to-beat variability is affected by the activity of the autonomic nervous system. Lehrer suggests that decreased HRV is evidence of vulnerability to physical and psychological stressors, and disease [20]. In contrast, higher HRV has been associated with creativity, psychological resilience, and a more developed capacity to control affective, cognitive, and physiological aspects of stress [27, 28], thus optimum variability is essential. Standard deviation normal to normal (SDNN) is often used as a measure of overall cardiovascular adaptability, while frequency domain analyses of HRV have been used to assess autonomic balance. High frequency (HF) HRV (0.15–0.40 Hz) reflects the inhibition and activation of the vagus nerves by breathing at normal rates. Low frequency (LF) HRV (0.05–0.15 Hz) associates highly with baroreflex gain, and is influenced by both the sympathetic and parasympathetic systems. The baroreflexes are important mechanisms for controlling blood pressure. the very low frequency (VLF) band (0.005–0.050 Hz) represents sympathetic activation or reduced parasympathetic inhibition [26, 29].

Resonant breathing biofeedback involves slowing the breathing rate to attain resonant frequency, which varies from one individual to another. Breathing at resonant frequency will maximize amplitude of respiratory sinus arrhythmia (RSA) and stimulate the baroreflex. RSA is a component of HRV; it reflects homeostatic activity and adaptability [29]. RSA refers to cyclical oscillation in heart rate coincident with the respiratory cycle, such that increases in heart rate occur during inhalation and decreases in heart rate during exhalation. Lehrer, Vaschillo, Vaschillo, et al. demonstrated that healthy participants who practiced resonant frequency breathing biofeedback regularly increased their baroreflex gain [30]. At the same time, as RSA increases, the spectral distribution of HRV moves. Now, a larger percentage of total variability resides in the LF range, including the 0.1-Hz point. Thus, HRV biofeedback is based on the premise that breathing at this resonant frequency will reinforce the baroreflexes and thus improve cardiovascular and autonomic stability and, indirectly, reduce emotional instability.

Techniques that increase RSA or HRV have been shown to benefit organizations by improving productivity, reducing health care costs, lowering absenteeism, and increasing retention [31, 32, 33]. Yet, to date no studies have been done on the use of HRV biofeedback, particularly resonant breathing biofeedback, in industrial operators. In clinical setting, both Siepmann, Aykac, Unterdörfer, et al. [19] and Karavidas, Lehrer, Vaschillo, et al. [21] showed that resonant breathing biofeedback had positive effects in treating depression. Moreover, Strack [34] and Lagos, Vaschillo, Vaschillo, et al. [35] found that a similar technique had positive effects in improving athletes' performance. These results suggest that resonant biofeedback training may help the athlete cope with the stress of competition and improve neuromuscular function. Strack [34] and Lagos et al. [35] also reported that LF HRV and amplitude of oscillation at 0.1 Hz considerably increased during biofeedback practice. An increase in percentage of LF HRV during biofeedback practice reflects resonance effects involving both RSA and baroreflex gain [30]. This suggested that being in a state of "resonance" is linked to enhanced performance. As an inexpensive, safe, and noninvasive technique, resonant breathing biofeedback may prove to be a

useful training approach to reducing stress-related symptoms in industrial workers.

The purpose of this study was to examine the effect of resonant frequency breathing biofeedback training on alleviating stress-related symptoms among manufacturing operators. We evaluated the degree and level of occupational stress in terms of depression, anxiety, and stress as they have been recognized as important mental outcome measures in a stressful workplace [36, 37, 38]. Furthermore, poor working conditions may be a significant predecessor of stress and may, therefore, contribute to the occurrence of depression or anxiety [39]. Our hypothesis is that workers in the biofeedback training group would report a reduction in depression, anxiety, and stress symptoms compared to those in the control group.

2. METHOD

2.1. Participants

This was an open label study; it used a combination of convenience selection and random assignment. The participants were recruited from a manufacturing company producing electronic parts located in Kuantan, Pahang, Malaysia. The study was approved by the Institutional Review Board of the Faculty of Medicine, International Islamic University of Malaysia. Forty-four female volunteers were screened for eligibility with the Nijmegen questionnaire to detect the presence of hyperventilation or abnormal breathing [40]. Those with scores of 23 or over were excluded from the study. Potential participants who suffered from diabetes and took medication that could decrease physiological or autonomic arousal were also excluded. Forty healthy participants met the inclusion criteria and signed and returned consent forms. They were then assigned randomly into the training and control groups. Further, one participant in the intervention group was unable to register a finger pulse and 3 participants in the control group dropped out before completion because of job resignation. Thus, there were 36 participants in the final sample used in analyses: 19 in the training group and 17 in the control group. They all completed both pre- to post-training assessment. Each participant who completed the study was debriefed and given a reimbursement of MYR 60[1]. Table 1 displays the participants' demographic characteristics.

2.2. Depression, Anxiety, and Stress Scale (DASS)

The DASS is a set of three self-report scales designed to distinguish between, and provide relatively pure measures of, the three related and clinically significant negative emotional states of

TABLE 1. Demographic Characteristics of the Study Sample

Characteristic	Total ($N = 36$)	Biofeedback ($n = 19$)	Control ($n = 17$)
Age			
M	36.30	35.60	37.10
SD	10.14	10.58	9.88
Education (%)			
no high school	13.8	10.5	17.6
high school	86.1	89.5	82.4
Years of working (%)			
<5	44.4	42.1	47.1
5–10	5.5	10.5	0.0
>10	50.0	47.4	52.9

Notes. No high school = under 7 years of school, high school = 9–11 years of school.

[1] MYR 1 = USD 0.312

depression, anxiety, and stress [41]. Each of the three DASS scales contains 14 items, divided into subscales of 2–5 items with similar content. The depression scale assesses dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest/involvement, anhedonia, and inertia. The anxiety scale evaluates autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect. The stress scale is sensitive to levels of chronic nonspecific arousal. It assesses difficulty relaxing, nervous arousal, and being easily upset/agitated, irritable/over-reactive, and impatient. The DASS scale ranges from 0 (*did not apply to me at all*) to 4 (*applied to me severely, or all the time*). Participants are asked to rate the degree to which they experienced each state over the past week. Scores for depression and anxiety are calculated by summing the scores for the relevant items. In general, the higher the total score for each subscale, the more severe the respective emotional syndrome problem. For most research purposes, it is much better to use DASS scores than attempt to divide a sample into "normal" versus "clinical", or "high" versus "low" [41]. In this study, the DASS was delivered in Bahasa Malaysia and was validated for the Malaysian population. This version of the DASS has a very good Cronbach's α of .84, .74, and .79 for depression, anxiety, and stress, respectively [42].

2.3. Physiological Measures

The physiological assessment measured HRV amplitude using the HRV spectral power analysis as a primary measure of HRV because it reflects the autonomic balance. The main focus of this study was directed to the percentage of the total power stems from LF activity. As RSA increases, simultaneously the spectral distribution of HRV shifts, with a greater percentage of total variability now existing in the LF range, including the 0.1-Hz point. An increase in LF HRV during biofeedback practice reflects resonance effects involving both RSA and baroreflex gain [30]. In addition, respiration rate was calculated in terms of BPM.

2.4. Psychophysiological Assessment

Physiological responses of the autonomic nervous system were measured with a noninvasive biofeedback system with an I-330 C-2 interface (J & J Engineering, USA) with 14″ Core Duo laptop computer. The participants sat in front of the computer in a temperature-controlled room. Two electrocardiogram sensors, one on each wrist, were secured under sports wristbands; a respiration-monitoring belt with sensors was placed around the upper abdomen. The laptop screen presented a respiration curve, instantaneous heart rate, and an on-line Fourier spectrum of heart rate, as biofeedback information to the participants.

Heart rate data were averaged across 1-s intervals at a sampling rate of 512 Hz. An HRV analysis program (Biosignal Analysis Group, Department of Physics, University of Kuopio, Finland) calculated a power spectrum density estimate for the RR intervals series. The estimate was then extracted to obtain each absolute power for three frequency bands: VLF, LF, and HF. The percentage of LF from total power was then calculated.

2.5. Experimental Procedure

In the first meeting after discussing the objectives and aims of the study, each participant read and signed an informed consent. A 10-min physiological stress profile assessment was then administered individually, ~10–15 min prior to the pre- and post-intervention. The percentage of LF power of HRV spectral activity and respiration rate were recorded during 4-min baseline, 2-min stressor (a modification of serial seven), and 4-min recovery period. The serial seven is the most universally used stress test in research and clinical practice [43]. The usual time-span of this stress test is 1–4 min. The experimenter asked the participants to count down from 207 by sevens. After that, the participants in both groups completed psychometric questionnaire DASS and performed cognitive tests. The post-assessment was conducted one week after the final training period, thus allowing for some measure of maintenance.

Training sessions were conducted in the training room of the factory. The intervention group received five sessions of HRV biofeedback training, one session per week. Each training session lasted ~30–50 min: 10-min session review, 5-min baseline, and 20-min resonant frequency training biofeedback. The participants in the control group received five 20-min sessions, in which they were monitored physiologically. They were provided with same feedback display as the training group but no instruction or biofeedback.

In the first session, the experimental group was introduced to the biofeedback equipment, the training method, and the protocol [44]. The resonant frequency of each participant was then determined by measuring HR oscillation amplitudes while the individual breathed for intervals of ~2–3 min at each of the following frequencies: 6.5, 6.0, 5.0, and 4.5 breaths/min. A "pacing stimulus" was provided for this purpose. The trainee breathed following a light display that moved up and down on the computer screen at the target respiratory rate. The participants were also trained to inhale abdominally and to exhale through pursed lips with exhalation longer than inhalation. At the end of first session, the participants were instructed to practice breathing at their resonant frequency on a daily basis at home, between sessions, and when feeling down or stressed, in a minimum of 5-min practice segments (20 min/day total). They were given a breathing guideline to use at home between sessions.

In the second and all subsequent sessions, the participants were given biofeedback. They were gradually taught to maximize the peak amplitude of RSA. This aspect of training was repeated until the participants were able to meet the criteria of maximizing spectral activity near 0.1 Hz while maintaining diaphragmatic breaths. As a manipulation check for the biofeedback, the percentage of LF activity was monitored for the intervention group during training sessions. Along with the resonant frequency training biofeedback, the participants in the intervention group attended to a mentally demanding (stressor) task: mental arithmetic in the form of a $x + y - z =$ problem. The task consisted of a series of 20 questions and was given in sessions 4 and 5. The participants solved the arithmetic problem while attempting to maintain resonance breathing.

2.6. Statistical Analysis

The effects of resonant frequency biofeedback training were assessed on each DASS scale (depression, anxiety, and stress), resonant frequency bandwidth LF, and respiration rate. Due to violation of normality assumptions, Wilcoxon signed-rank tests were conducted to assess any significant reduction for depression, anxiety, and stress in each group from pre- to post-intervention. Resonant frequency bandwidths in LF activity and BPM were collected during stress profile before and after the training period. Three-way repeated measures analysis of variance (ANOVA) was used to analyze physiological data between groups across the three periods (baseline, stress, recovery) from pre to post. To examine training progress across five sessions, a two-way repeated measure ANOVA was conducted to evaluate physiological change of both the training and control group. The statistical analysis of all data was carried out with SPSS version 15. The level of significance was $p < .05$ for all tests.

3. RESULTS

3.1. Group Equivalence

The effectiveness of random assignment in achieving pretest group equivalence was examined with t tests and χ^2 test. The intervention and control groups did not significantly differ by age (t (34) = –0.449, p = .656), years of working (χ^2 (2) = 1.895, p = .388), or education (χ^2 (1) = 0.380, p = .537). No pretraining differences were found between groups with respect to all baseline scores of depression, anxiety, and stress (t (34) = –1.887, p = .068; t (34) = –0.344, p = .733; respectively). An analysis of the stress profile revealed no significant differences between the biofeedback and the control group on each frequency bandwidth (VLF, LF, and HF) and BPM across the three conditions (baseline, stressor, recovery); all $p > .05$.

3.2. Manipulation Check

Training effectiveness between groups and within sessions was evaluated via two-way ANOVA with repeated measures on percentage of total HRV power shifted to the LF range. The result showed a significant interaction for session by group, $F_{(1, 34)} = 10.615$, $p < .001$, as well as a significant difference between groups for percentage of LF power, $F_{(4, 136)} = 44.831$, $p < .001$. A separate analysis with one-way repeated measure ANOVA revealed that the par-
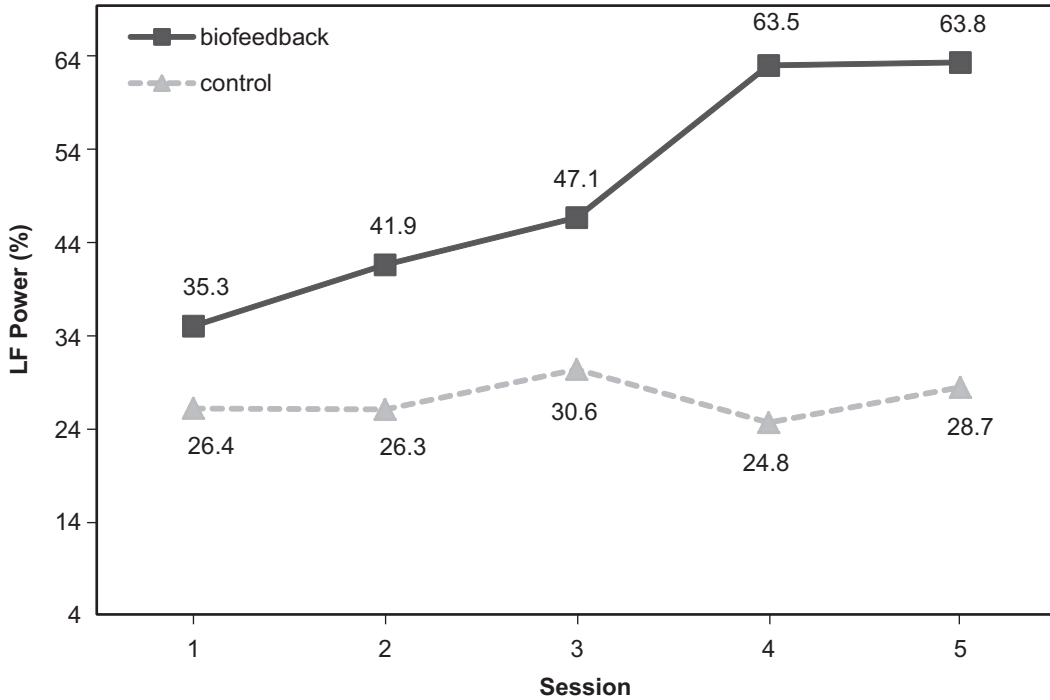

Figure 1. Manipulation check: participant progress in low frequency (LF) activity across 5 sessions for both groups.
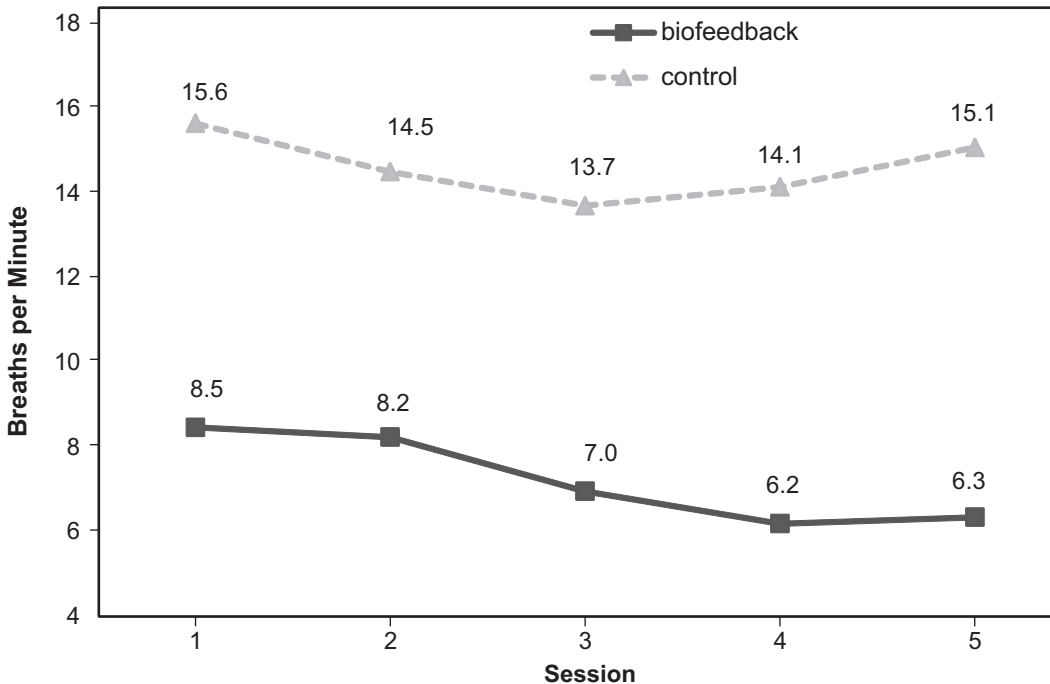

Figure 2. Manipulation check: participant progress in breaths per minute across 5 sessions for both groups.

ticipants in the biofeedback group made significant progress in their learning over sessions, $F(4, 72) = 16.208$, $p < .001$, as opposed to the control group, $F(4, 64) = 0.756$, $p = .558$. Figure 1 depicts improvement in LF activity across five sessions.

Nonparametric Friedman tests were conducted to compare the breathing rate across five sessions in each group as respective data were found not normally distributed. Figure 2 shows that the breathing rate of the biofeedback participants significantly changed over the five sessions, $\chi^2(4) = 20.660$, $p < .001$, as opposed to of the control participants, $\chi^2(4) = 6.286$, $p = .179$. Although the changes in BPM were significant only between sessions 2 and 3, 4, and 5, the overall breathing rate tended to decrease throughout all sessions.

3.3. DASS

The biofeedback group reported a significant decrease in the DASS score compared to the control group from pre- to post-intervention. Table 2 shows the median and 25–75th quartile of the DASS scores at pre- and post-training for each scale. The result of Wilcoxon signed-rank test showed that the participants in the biofeedback group reported a significant lower score on depression ($Z = -2.826$, $p = 0.002$, large effect size $r^2 = .420$), anxiety ($Z = -2.854$, $p = .001$, large effect size $r^2 = .429$), and stress ($Z = -2.733$, $p = .002$, a large effect size, $r^2 = .393$). On the contrary, the control group did not report any significant reduction on DASS-Depression ($Z = -1.732$, $p = .083$, $r^2 = .113$), DASS-Anxiety ($Z = -1.518$, $p = .129$, $r^2 = .078$), and DASS-Stress ($Z = -1.414$, $p = .157$, $r^2 = .027$).

3.4. Physiological Stress Profile

At pretraining, both groups showed reactivity to stress compared to baseline and recovery periods as measured by LF activity. There were no significant differences between groups or within group on LF activity and BPM at baseline, stress, or recovery. Figure 3 illustrates percentage of LF values from pre- to post-training by group and assessment period. A three-way repeated measures ANOVA demonstrated that there was a significant main effect for time, $F(1, 34) = 20.757$, $p < .001$, and a significant time × group interaction on percentage of LF activity, $F(1, 34) = 9.350$, $p = .004$. There was a between-group difference, $F(1, 34) = 4.218$, $p = .048$. However, no significant effect was found for condition, $F(2, 68) = 1.682$, $p = .194$, or condition × group, $F(2, 68) = 2.477$, $p = .092$, or an interaction between time and condition, $F(2, 68) = 0.337$, $p = .715$. Within-group analysis using a paired t test for dependent samples revealed that after training the biofeedback, the participants increased their HRV power toward LF activity at baseline, $t(18) = -4.119$, $p < .001$; stressor $t(18) = -3.352$, $p = .002$; and recovery, $t(18) = -2.789$, $p = .006$; as opposed to the control group, $t(16) = 0.718$, $p = .241$; $t(16) = -1.354$, $p = .098$; t$(16) = -1.013$, $p = .163$.

A similar result was also found on breathing rate measure. Both groups showed no difference in the breathing pattern at pre- and post-training with the highest breathing rate during the stressor period (Figure 4). A group × time × condition repeated measures ANOVA revealed a significant main effect for time, $F(1, 34) = 25.236$, $p < .001$, and for conditions, $F(1, 34) = 8.337$, $p = .001$.

TABLE 2. Median and 25–75th Quartile for DASS Scores from Pre- to Post-Training

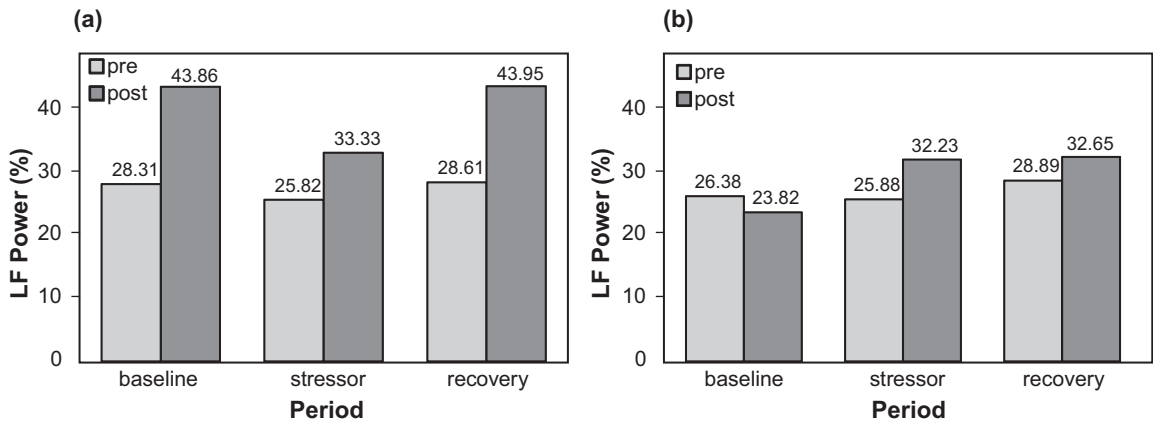| DASS | Group | Pre-Training | | Post-Training | |
		Mdn	25th–75th Quartile	Mdn	25th–75th Quartile
Depression	biofeedback	12	5.0–16.0	5	2.0–8.0
	control	10	4.0–13.0	4	2.5–11.0
Anxiety	biofeedback	8	6.0–18.0	5	3.0–14.0
	control	11	7.5–14.0	11	7.5–14.0
Stress	biofeedback	13	9.0–21.0	9	6.0–12.0
	control	11	6.5–18.5	10	8.0–16.0

Notes. DASS—depression, anxiety, and stress scale.

Figure 3. Percentage of low frequency (LF) power at pre- and post-training by group and assessment period: (a) resonant biofeedback, (b) control.
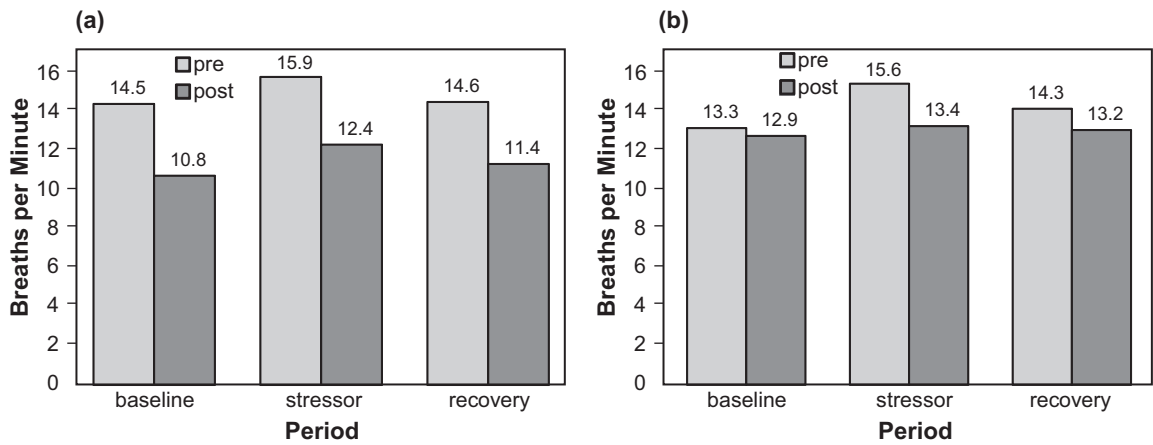

Figure 4. Breathing rate at pre- and post-training by group and assessment period: (a) resonant biofeedback, (b) control.

There was also a significant group × time interaction, F (1, 34) = 5.731, p = .022. However, the between-group effect was not significant, F (1, 34) = 0.456, p = .456. Although the participants in both groups showed a decrease in BPM over time at all periods, the results were significant only in the biofeedback group (all p < .01). Furthermore, the results did not show a significant interaction effect on condition × group, F (1, 34) = 0.138, p = .872, or on time × condition × group, F (1, 34) = 0.526, p = .593.

4. DISCUSSION

In general, the results of this study revealed that a 5-week course of resonant biofeedback training had significant positive effects on a group of operators. The participants in the biofeedback group showed significant improvements from baseline to follow-up assessment in self-reported negative emotional symptoms. The depression, anxiety, and stress scores were significantly lower in the intervention group than in the control group. Throughout five sessions of training, the biofeedback group also showed a significant increase in LF activity (Figure 1). This HRV data confirms that the participants learned how to effectively regulate activity in the autonomic nervous system that continued to homeostasis balance. Similar results were not present in the control group.

A remarkable shift toward LF activity was found in the biofeedback participants in the physiological stress profile. They were also able to master slow diaphragmatic breathing. At pretraining, the participants in both groups showed reactivity to stress. Post-training assessment revealed

that both groups habituated to the stressor. However, there was a significant decrease in BPM in the biofeedback group, with none in the control group. Apparently, the training participants used the slow diaphragmatic breathing technique during the stressor condition, even though there was no special instruction.

This study also revealed that resonant biofeedback produced a significant decrease in depression (58.3%), anxiety (37.5%), and stress (30.8%) scores in the biofeedback training group from pre- to post-intervention. The respective values of effect size were also reported high, suggesting the effects of biofeedback training in reducing negative emotional symptoms; a substantive finding. The mechanism for emotional effects may be a biofeedback effect on autonomic regulation. Resonant frequency breathing biofeedback induces high-amplitude oscillations in cardiovascular functions, which in turn train autonomic reflexes [30]. Lehrer and Vaschillo explained that training these reflexes restored autonomic balance or homeostasis and improved autonomic control that supported emotional regulation [45]. As such, this technique may have been responsible for the significant reduction in the workers' negative emotional symptoms.

The results of this present study are in line with previous studies on the effect of HRV biofeedback in depressed patients [19]. Karavidas et al. found that participants in HRV biofeedback demonstrated alleviation in several indices of depression, such as sleep hygiene, fatigue, and concentration [21]. Although the correlation between the amplitude of changes in physiological variables and the magnitude of changes in depression was not established, alleviation in depressive levels was paralleled with an increase in LF HRV at session 4, where there was a significant reduction in symptoms. These findings suggest that symptom reduction occurred at the point where the patient had maximally learned the skill of resonant frequency breathing. Moreover, in a case study of a young golfer, HRV biofeedback training enhanced his ability to cope with anxiety and various other negative mood states, which sequentially improved his athletic performance [35]. This was also supported by an increase in

both total HRV and LF activity within and between sessions. Likewise, Zucker, Samuelson, Muench, et al. showed that HRV biofeedback significantly decreased symptoms of post-traumatic stress disorder among patients after 4-week training [18]. Increases in HRV measured with SDNN were significantly associated with a reduction in symptoms of post-traumatic stress disorder. Although prior studies mostly applied to patients, consistent results were obtained in this study with healthy participants. All of these results support the efficacy of HRV biofeedback in improving physiological and psychological functions among industrial workers.

Regarding its effect size, the magnitude of the training effect reduction in each emotional symptoms is large (r^2), ~0.40. Although this value might be amplified because of small sample size, these findings are still impressive when taking into consideration the unique effect of HRV biofeedback without supplementary skills, e.g., cognitive coping strategies, time management [46]. Our effect size surpasses the effect size reported by Kelley [46]. In his meta-analysis study, he revealed a small effect of biofeedback intervention either in industry ($d = 0.28$) or nonindustry settings ($d = 0.35$). However biofeedback interventions reviewed in Kelley's study were mostly aimed at controlling tonic level of muscle tension, blood pressure, skin temperature—tasks that are clearly more difficult than learning to increase HRV [20]. Rather than trying to teach people change tonic levels of physiological arousal functions, the resonant breathing (HRV) biofeedback method is directed to exercise and strengthen one of the body's important self-modulatory reflexes: the baroreflex. Due to the pervasive effects of the baroreflex in maintaining autonomic and emotional stability, this method may be useful for treating emotional regulation (anxiety and depression) [45]. Thus, it is plausible that resonant breathing biofeedback training results in a more encouraging effect than those other types of biofeedback.

Concerning its practical issue, resonant breathing biofeedback training may be combined with other interventions to obtain better outcomes and long-term benefits. It can be embedded in a stress management program which generally consists of

various interventions, such as cognitive coping strategy, exercise, assertiveness, and communication training [5, 31, 32, 33]. As this study had a small sample size and a homogenous sample (i.e., female operators in electronic manufacturing industry), the results may not generalize to other populations. A definitive conclusion also cannot be made about the role of autonomic changes in alleviation of depression, anxiety, and stress. Another limitation is that it is still unclear whether the immediate training effects of HRV biofeedback enlarge, decrease, or remain consistent over time. Longitudinal research is thus warranted.

In summary, resonant breathing biofeedback training demonstrates promise for the new training approach for reducing negative emotional states in manufacturing operators. Our data suggest that the participants learned successfully to shift their HRV toward LF range as well as regulate their respiration rate in a relatively short time. Parallel findings between reduction in stress-related symptoms and improved physiological variables may be attributed to being in a state of "resonance" or autonomic nervous system (i.e., homeostasis) balance. These findings are consistent with previous research indicating that maximal control over HRV at the resonant frequency can be obtained in most people after approximately four sessions of training [18, 20, 30]. Future studies are warranted in larger and heterogeneous samples and other industries as well as to further clarify the interrelationship between autonomic functioning and emotional symptoms.

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