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Exploring the Effectiveness of a Computer-Based Heart Rate Variability Biofeedback Program in Reducing Anxiety in College Students

Gregg Henriques · Steven Keffer · Craig Abrahamson · S. Jeanne Horst

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Abstract Given the pervasiveness of stress and anxiety in our culture it is important to develop and implement interventions that can be easily utilized by large numbers of people that are readily available, inexpensive and have minimal side effects. Two studies explored the effectiveness of a computer-based heart rate variability biofeedback program on reducing anxiety and negative mood in college students. A pilot project ($n = 9$) of highly anxious students revealed sizable decreases in anxiety and negative mood following utilizing the program for 4 weeks. A second study ($n = 35$) employing an immediate versus delayed treatment design replicated the results, although the magnitude of the impact was not quite as strong. Despite observing decreases in anxiety, the expected changes in psychophysiological coherence were not observed.

Keywords Anxiety · Biofeedback · Heart rate variability · Heart rhythm coherence

G. Henriques (✉)
Graduate Psychology, James Madison University, Harrisonburg, VA, USA
e-mail: henriqgx@jmu.edu

S. Keffer
Department of Biology, James Madison University, Harrisonburg, VA, USA

C. Abrahamson
Department of Psychology, James Madison University, Harrisonburg, VA, USA

S. Jeanne Horst
Department of Psychology, Eastern Mennonite University, Harrisonburg, VA, USA

Introduction

In a recent large-scale survey, almost one-third of college students reported that stress and anxiety had negatively affected their academic performance and 12% reported having experienced an anxiety disorder in the previous year (American College Health Association National College Health Assessment Spring 2006). Moreover, the levels of anxiety and prevalence of anxiety disorders appears to be increasing; a meta-analysis of American college students and children found that anxiety scores increased by about a standard deviation between 1952 and 1993 (Twenge 2000). Anxiety disorders are currently treated with drugs and/or psychotherapy, but both of these approaches can be relatively expensive and require highly trained professionals to administer. Given the pervasiveness of anxiety and anxiety disorders, it is important to develop and implement interventions that can be easily utilized by large numbers of people that are readily available, inexpensive and have minimal side effects. Some computer based CBT programs for anxiety have been developed and research suggests they can be effective (Zetterqvist et al. 2003). However, these programs are often done in conjunction with therapy or require a series of training sessions for individuals to learn and there tends to be a relatively high drop-out (Reger and Gahm 2009). Our specific interest has been to find stress reduction interventions that can be utilized in a self-directed way by the many university students suffering from anxiety. Consequently, we examined an out-of-the-box computer-based heart rate variability biofeedback stress reduction program to determine if it would be effective in reducing anxiety in college students.

Heart rate variability (HRV) is the beat-to-beat changes in heart rate (Task Force of the European Society of Cardiology and The North American Society of Pacing

Electrophysiology 1996), and provides an index of autonomic signals to the heart, with low HRV indicating decreased vagal nerve activity and increased sympathetic activity. Low HRV and diminished vagal tone are associated with multiple physiopathologies including fetal distress, diabetic autonomic neuropathy, hypertension, stroke, higher risk of mortality after myocardial infarction, and immune system dysfunction (Task Force of the European Society of Cardiology and The North American Society of Pacing Electrophysiology 1996; Stein and Kleiger 1999; Thayer and Sternberg 2006). Low HRV has also been linked to diminished emotional and cognitive regulation (Thayer and Lane 2009) and associated with multiple psychopathologies including panic disorder, posttraumatic stress disorder, generalized anxiety disorder, and phobic anxiety (Friedman 2007).

There is evidence to suggest that interventions that enhance vagal tone and increase HRV may have a salutary effect on anxiety. Friedman (2007) lists three such interventions: (1) Zen meditation in which focused attention on measured breathing is important; (2) affect management techniques that reduce negative emotion and increase positive emotion; (3) relaxing music. Two common HRV biofeedback techniques employ the first two of these interventions, regulation of breathing and cultivating positive affect. Resonant frequency HRV biofeedback (RF-HRV) regulates breathing at about five-six breaths per minute, a rate that matches the "resonant frequency of the cardiovascular system (CVS) at about 0.1 Hz" (Hassett et al. 2007). RF-HRV improves the symptoms of anxiety (Reiner 2008), depression (Karavidas 2005), fibromyalgia (Hassett et al. 2007) and chronic obstructive pulmonary disease (Giardino et al. 2004). HeartMath HRV biofeedback, the subject of this study, focuses on changing negative affect to positive, and the latest iteration of this technique also includes paced breathing. In this study, we tested the biofeedback technique, Freeze-Frame, developed and marketed by HeartMath, LLC. As originally formulated, the Freeze-Frame technique was a five-step method for shifting affect from negative to positive when feeling stressed. Specifically, individuals were instructed to do the following: (1) Recognize the stressful feeling, and Freeze-Frame it (take a time out); (2) Make a sincere effort to shift your focus away from the racing mind or disturbed emotions to the area around your heart; (3) Recall a positive, fun feeling or time and attempt to re-experience it; (4) Using your intuition, common sense, and sincerity, ask your heart what a more efficient response to the situation would be, one that would minimize future stress; and (5) Listen to what your heart says in answer to your question (Tiller et al. 1996).

The use of computer-based biofeedback with the Freeze-Frame method is first mentioned in the literature by McCraty et al. (2000), and has evolved slightly over time. As described below, we explored the effectiveness of this program in a pilot study and then in a larger study with an immediate versus delayed treatment design. Our pilot study used HeartMath's Freeze-Framer 2.0 (2005) biofeedback software, and our immediate versus delayed treatment study used the successor to Freeze-Framer 2.0, emWave PC 1.0 (2007). In Freeze-Framer 2.0 there are three steps to what is called Quick Coherence: "(1) Heart Focus. Shift your attention to the heart area. Focus on the area in the center of your chest; (2) Heart Breathing. Pretend your breath is flowing in and out through your heart area. Breathe slowly and gently. Find a natural inner rhythm that feels good; (3) Heart Feeling. Continue to breathe through the heart area. Recall a positive feeling and re-experience it. Feel the feeling and sustain it. Appreciation, Care." The emWave PC 1.0 software Quick Coherence also has three steps, but there is one important difference. In step 2, heart breathing, the instruction is to breathe through the heart at a rate of 5–6 breaths per minute. This recommended breathing rate is the same rate used in RF-HRV biofeedback programs. Thus, emWave PC 1.0 Quick Coherence explicitly combines two factors associated with enhanced HRV, the cultivation of positive affect and paced breathing aimed at attaining a resonant frequency.

Central to the HeartMath biofeedback system is the concept of Heart Rhythm Coherence. The authors of this system claim "heart rhythms associated with positive emotions, such as appreciation, are clearly more *coherent*—organized as a stable pattern of repeating sine waves—than those generated during a negative emotional experience. A coherent heart rhythm can therefore be defined as a relatively harmonic (sine-wave-like) signal with a very narrow, high-amplitude peak in the LF (Low Frequency) region [around 0.1 Hz] of the HRV power spectrum and no major peaks in the VLF (Very Low Frequency) and HF (High Frequency)" (McCraty et al. 2006, pp. 7–8). McCraty and colleagues argued a general index of coherence is found in the ratio LF/(VLF + HF). The degree of coherence, described in greater detail in the methods section, is the primary variable on which participants receive the feedback.

To our knowledge there has been no test of the efficacy of the Freeze-Framer 2.0 or the emWave PC 1.0 software as a stand-alone, biofeedback method. There have been several studies testing stress reduction programs that included Freeze-Frame biofeedback, such as the Heart of Wellness Program (McCraty et al. 2000), Power to Change Performance (McCraty et al. 2003) and TestEdge Program (Bradley et al. 2007). As Freeze-Frame biofeedback was but one component of these studies, it is impossible to say what role it played relative to the other study components in the results. The purpose of the present investigation is to

examine the effectiveness of the HeartMath biofeedback software program as a stand-alone intervention for reducing anxiety and improving well-being in college students.

Study 1: Pilot

Methods

Participants and Screening Procedures

One hundred and fifty-eight introductory psychology students at a midsized, mid-Atlantic University were screened in an introductory psychology class for the presence of anxiety via self-report measures and their interest in participating in a study exploring biofeedback for anxiety. One hundred and fourteen expressed an interest, and were screened for the presence of anxiety based on their scores on two subscales (General Distress, Anxiety and Anxious Arousal) from the Mood and Anxiety Symptom Questionnaire (see below for description of the measure). The students were ranked highest to lowest based on their combined scores from the subtests, and the top twenty were contacted. Nine students declined, and 11 were interviewed regarding their motivation and ability to participate. Participants were excluded if they were not concerned about their anxiety, if they were not interested in biofeedback or if there had been changes in their psychotropic medication or psychotherapy within the last 3 months. One student was eliminated and ten students were chosen to participate; however, one student dropped out shortly after the study began, resulting in a total of nine participants (seven women and two men) completing the computer-based biofeedback procedure.

At the beginning of the study, the students acknowledged experiencing anxiety and their scores on self-report measures of state and trait anxiety were high, averaging approximately two standard deviations above the norm (Spielberger 1970). The participants provided informed consent during the initial screen for participation in the biofeedback portion of the study. They received course credit in return for their participation.

Biofeedback Software

Freeze-Framer 2.0 is a computer-based biofeedback technique developed and marketed by HeartMath LLC. A finger pad or ear sensor tracks the user's heart rate. A Heart Rhythm graph displays a real-time Fast Fourier Transform of the heart rate intervals. According to the product, a jagged graphical pattern indicates low coherence, stress and anxiety, whereas a smooth, sine wave-like pattern is an indication of high coherence, well-being and less stress. A Coherence Bar Chart (CBC) displays the percentage of time a user has spent in three categories of Coherence: low, medium and high. These proportional bars are color-coded and have accompanying audio signals as shifts in coherence occur. An Accumulated Coherence Score (ACS) is a measure that allows the user to assess her/his performance over the course of a biofeedback session. The ACS is computed every 5 s with two points for high coherence, one point for medium coherence and negative one point for low coherence. Thus, the graphical line of the ACS will have a positive slope when medium and high coherence predominate, but will show a negative slope when low coherence predominates. By practicing the Quick Coherence method, users attempt to smooth the Heart Rhythm graph, increase the percentage of time spent in medium and high coherence as revealed by the CBC and maintain a positive slope with the ACS. Users can track their progress via a graphical display of coherence-level ratios for each session, displayed consecutively and color coded in the same fashion as the CBC.

Freeze-Framer 2.0 has four challenge levels. Challenge levels are the settings at which the participant's coherence score is judged to be low, medium or high, with high challenge levels requiring higher scores for medium or high coherence. At the initial training with a Research Student Supervisor (RSS—these were undergraduate psychology and biology majors working with the authors to conduct the study) participants found a challenge level that was comfortable (one in which they could experience some success at shifting from lower to higher coherence, develop a smoother heart rhythm graph, and show a higher percentage of coherence in the Coherence Bar Chart). Participants were told they could select a higher, more difficult challenge level when they were able to consistently achieve high coherence over several sessions. Thus, the choice of a challenge level over the course of the intervention was left to the participants.

Lab Facilities

An office space in the basement of the biology building was made available with two computers loaded with the HeartMath software. Participants had access to the office at any time of the day.

Measures

The Mood and Anxiety Symptom Questionnaire (MASQ). The MASQ (Watson and Clark 1991; Watson et al. 1995) is a 90-item measure of mood and anxiety symptoms based on the tripartite model of negative affect. Respondents indicate the extent to which they experienced each symptom during the past week on the following scale: 1 = not at

all to 5 = extremely often. The scale consists of six subscales: (1) General Distress, Mixed (GDM) (2) General Distress, Anxious (GDA) (3) General Distress, Depressed (GDD) (4) Anxious Arousal (AA) (5) Lost of Interest (LOI) and (6) High Positive Affect (HPA). The MASQ subscales have been found to have adequate convergent and discriminant validity, as well as good internal consistency in student and adult volunteer samples. This was also the case with a clinical sample of patients receiving treatment for substance use disorders (Watson et al. 1995). The MASQ was administered a total of seven times, initially to obtain a baseline, weekly during the biofeedback procedures, 1 week post intervention and, finally, 4 weeks post intervention.

The State Trait Anxiety Inventory (STAI). The STAI (Speilberger, 1970) is a widely used measure of anxiety proneness and anxiety levels. Participants rated 40 items (20 assessing state anxiety and 20 assessing trait anxiety) using a 4-point Likert scale ranging from 1 (almost never) to 4 (almost always). Psychometric properties of the STAI are well documented (Spielberger 1970). The STAI has demonstrated high internal consistency ($\alpha = .90$), good test–retest reliability ($r = .70$–$.76$), and concurrent validity with other anxiety measures. The STAI was administered the week prior to and the week following the conclusion of the biofeedback sessions, allowing for pre-post comparisons.

Procedures

The study was approved by the Institutional Review Board at James Madison University and took place in spring 2007. After the participants were identified, screened, and provided informed consent, the study began with an introduction and overview of the HeartMath product, Freeze-Framer 2.0. Participants were given a 45-min description of how to use the software and the theory behind it, and a description of this presentation is available from the authors. Video clips provided on the Freeze-Framer 2.0 CD were presented that included information on stress, the physiological reaction to stress, psychophysiological coherence, the relationship between the heart and the brain, and the Quick Coherence technique. Participants were reminded of their responsibilities. They were to use the biofeedback program 20 min a day, 5 days a week (they were free to choose the time of day that best suited their schedule) and submit weekly MASQ questionnaires. Participants were assigned an RSS. After the introductory presentation, the RSSs took the participants to the lab space and showed them how to log into the computer, begin the HeartMath software, hook up the sensor, monitor the feedback and save each biofeedback session. They also reviewed the instructions for Quick Coherence. In addition, they explained about the challenge levels and helped participants find an appropriate challenge level. The RSSs issued and collected from the weekly MASQ scale and were available to answer questions throughout the 4 weeks of the study. The participants also completed the MASQ and STAI the week after the study was completed (Final). Four weeks, later the participants were contacted a final time and asked to complete a follow-up MASQ.

Results from Study 1

Table 1 provides the means on the MASQ and STAI subscales for each time point. The STAI subscales were given at baseline and the week following completion (Final). Despite the small sample size, paired t tests of the STAI subscales revealed decreases in both the State, $t\,(1, 8) = 2.93$, $p = .019$ and the Trait domains, $t\,(1, 8) = 2.58$, $p = .032$. The changes were substantial; for example, the

Table 1 MASQ and STAI subscale scores means for each study time point

MASQ subscale	Baseline ($n = 9$)		Time 1 ($n = 8$)		Time 2 ($n = 6$)		Time 3 ($n = 9$)		Time 4 ($n = 8$)		Final ($n = 9$)		4 week Post ($n = 8$)	
	M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
GDM	56.2	7.58	46.8	9.34	41.2	11.3	43.7	9.71	42.3	7.25	38.6	11.7	43.1	9.83
GDA	36.9	5.46	29.5	7.91	18.7	5.42	28.7	9.35	28.8	5.94	21.8	8.28	24.0	5.45
GDD	43.7	7.03	39.1	9.23	27.8	10.5	33.4	11.1	36.9	9.79	27.1	8.68	31.4	10.8
AA	40.8	4.41	34.0	8.22	24.8	6.64	28.9	9.59	28.9	9.37	22.3	7.00	26.1	6.51
LOI	22.3	5.48	19.9	4.35	15.3	4.0	17.0	4.97	20.4	3.70	15.3	5.17	18.0	5.90
HPA	58.6	11.0	58.8	13.1	71.3	12.8	70.3	10.0	58.6	12.5	69.3	10.3	71.0	15.5
STAI-S	59.8	11.1									44.4	12.0		
STAI-T	59.0	5.6									51.4	9.81		

MASQ Mood and anxiety symptom questionnaire, *STAI* State trait anxiety inventory, *GDM* General distress-mixed, *GDA* General distress anxiety, *GDD* General distressed-depressed, *AA* Anxious Arousal, *LOI* Loss of interest, *HPA* High positive affect, *STAI-S* State trait anxiety inventory-state, *STAI-T* State trait anxiety inventory-trait

percentile rankings on the State scale for the group went from the 99% to the 60%, indicating a shift from disordered levels of anxiety to anxiety levels in the normal range.

Full MASQs were given at baseline; following each week of participation (Times 1 thru 4); the week following completion (Final); and 4 weeks post intervention. As depicted in Table 1, the means generally showed a decreasing pattern for the negatively valenced subscales. Paired t tests with a Bonferroni correction ($p < .008$) for the six MASQ subscales comparing the baseline scores to the final scores revealed significant differences in the expected direction on four of the six MASQ subscales, including General Distress, Mixed; General Distress, Anxious; Anxious Arousal; and General Distress, Depressed (GDM Mean Difference = 17.7, SD = 7.7, t (1, 8) = 6.9, $p < .001$; GDA Mean Difference = 15.1, SD = 8.3, t (1, 8) = 5.4, $p = .001$; GDD Mean Difference = 16.6, SD = 11.4, t (1, 8) = 4.3, $p = .002$; AA Mean Difference = 18.2, SD = 7.5, t (1, 8) = 7.2, $p < .001$; LOI Mean Difference = 7.3, SD = 8.7, t (1, 8) = 2.5, $p = .035$; HPA Mean Difference = −10.8, SD = 16.4, t (1, 8) = −1.9, $p = .083$).

Study 1 Discussion

The results of the pilot study were promising and suggested that participating in the HeartMath computer-based biofeedback intervention resulted in a reduction in self-reported levels of anxiety and negative mood. Overall pre-post comparisons of the two subscales from the STAI and five of the six subscales of the MASQ decreased in the expected direction, suggesting that the participants' levels of negative affect had decreased during the course of the study. The conclusion from the pilot is that the computer-based biofeedback intervention may provide significant reduction in self-reported levels of anxiety and negative mood.

There were several limitations of this study. First was the small sample size, which obviously raises questions about the generalizability of the results. Second, the selectivity of the sample was quite high in that we screened over a hundred individuals, but only included nine. Third, there was no control group and thus it remains possible that the reduction in symptoms was a function of regression or of taking the measures repeatedly. Fourth, we were unable to conduct analyses corresponding the changes in self-report to the coherence data recorded by computer-based biofeedback program. Specifically, the claims made by the HeartMath LLC company are that improvements in levels of negative mood and anxiety should be associated with increases in an individual's capacity to obtain and maintain a state of psychophysiological coherence. If this is the case, then there should have been increases in these data associated with the changes in the self-report.

Our second study employed an immediate versus delayed treatment design to address the questions raised by the pilot data. Specifically, we undertook this study to determine: (a) if the findings of a pre-post decrease in self-reported levels of anxiety and depressed mood would be replicated; (b) if the intervention would have a significant impact on other aspects of mental health, such as broad domains of well-being; (c) whether changes in self-reported levels of anxiety and negative mood would be significantly greater in the intervention than a control group of participants filling out the same measures on a weekly basis; and (d) whether changes in self-report levels on the MASQ would be significantly related to changes in measures of psychophysiological coherence.

Study 2: Immediate Versus Delayed Treatment

Participants

Our goal was to place 25 participants in each of two groups, one of which would receive the intervention initially and the other subsequent to the completion of the first. Ninety-two students responded to our recruitment efforts (see below for details about recruitment) and participated in an initial screening for the study. Seventy-one students were subsequently interviewed for interest and eligibility (see below for details about the interviews); 51 of the interviewees were invited to participate in the study, eleven were eliminated, and nine were identified as alternates. Via coin toss, 26 were randomly assigned to Group A and 25 to Group B. Four students in Group A and eight in Group B declined to participate in the study shortly after group assignment. One student asked to transfer from Group A to Group B. Three alternate students were invited to join Group A, one accepted. Six alternate students were invited to join Group B, five accepted. Thus at the onset of the study there were 22 students in Group A, 18 females and four males, and 23 students in Group B, 19 females and four males. Over the course of the study, five females dropped out of Group A and five females dropped out of Group B. Thus, at the study's conclusion there were 17 students in Group A (13 females, 4 males) and 18 students in Group B (14 females, 4 males).

Biofeedback Software and Hardware

The emWave PC 1.0 software used in the second study was nearly identical to the Freeze-Framer 2.0 used in the pilot.

As noted in the introduction, the instructions for attaining coherence were slightly different. However, the computer interface was the same. In addition to the desktop biofeedback, participants were given a handheld biofeedback device marketed by HeartMath, the emWave Personal Stress Reliever. Users placed their index finger on a sensor pad and a LED display provided feedback about the user's coherence level: a red color was displayed for low coherence, blue for medium coherence and green for high coherence. Thus, the color-coding of the handheld device matched the Coherence Bar Chart (CBC) of the desktop emWave PC 1.0 software. After receiving training on the handheld device, participants were issued their own device to carry with them throughout the 4 weeks of their intervention. They were told to use the handheld at times of their own choosing.

Lab Facilities

The lab facilities were changed from those used in the pilot study, in part to allow for more participants. Instead of one room in the biology building, 10 individual rooms located in the Department of Psychology laboratories were provided for the participants. Each individual lab room had a personal computer system that included both the emWave PC 1.0 software and finger or ear sensor. Participants had access to these rooms throughout the day and evening and, by arrangement with their RSS, on weekends.

Measures

The Mood and Anxiety Symptom Questionnaire (MASQ; see Pilot Study)

Scales of Psychological Well-Being (SPWB). Ryff (1989) introduced this scale as an instrument to measure those aspects of psychological functioning that were "missing" in a subjective well-being approach. The original version of the scale consisted of 120 items, with 20 items representing each of the six subscale dimensions: self-acceptance, positive relations with others, autonomy, environmental mastery, purpose in life and personal growth. The scale was later reduced to the 54-item version used in this study (Ryff and Keyes 1995). Each item is answered using a six-point Likert-type scale (1 = Strongly Disagree, 6 = Strongly Agree) with nine items written to represent each of the six subscales. The possible scores range from 9 to 54 for each of the subscales, with higher scores indicating greater well-being. Adequate-to-good psychometrics have been demonstrated with this scale, including solid internal consistency and good convergent and discriminant validity (e.g., Ryff and Keyes 1995).

Procedures

An immediate versus delayed research design was employed. This design was chosen because it both affords for comparison and allows each participant to receive the intervention.

In order to achieve an adequate target pool a mass e-mail message was sent to all undergraduates explaining the study and soliciting participants. Posters were placed around campus, table tents were placed in the student dining rooms and announcements were posted on the university webpage. Interested students were instructed to contact a study author to set up an interview or to find out more about the study.

The interview included a screen with the AA and GDA MASQ subscales and a 10-min face-to-face conversation inquiring about the kinds of anxiety-related symptoms the individual experienced, the importance of reducing those symptoms, if they had recently entered psychotherapy or changed medication for anxiety or depression, their awareness of biofeedback and interest in trying techniques to reduce their anxiety. An explanation of computer-based biofeedback was provided as well as a detailed description of the study requirements: an orientation, conducting the biofeedback procedure 5 days a week, 15-min a day, for 4 weeks, filling out weekly self-report measures for 9 weeks, and completing an exit interview. Following this description, potential participants were asked to rate their interest and motivation to participate on a scale of one to 10.

The inclusion/exclusion criteria for the study were as follows: (1) A per item mean score of two or greater on the MASQ AA and GDA subscales. This translates into approximately the top twenty percent of MASQ scorers for this population. Participants were excluded if they had a per item mean score of less than two on the MASQ AA and GDA. (2) An interest and motivation score of seven or greater on a one to ten scale. (3) Participants were excluded if they were not concerned about their anxiety or if they were not interested in biofeedback. (4) Although we initially planning on excluding individuals who had changed medications or psychotherapy in the past 3 months, we experienced some difficulty in recruitment and ended up including three students in group A and two students in group B who had started medication in the past 3 months.

As with the pilot, this study began with introductory sessions, one for each group. Participants provided informed consent and filled out the full MASQ and SPWB, which served as baseline assessments. The responsibilities of the participants were carefully reviewed. Participants were to use the desktop biofeedback system five times per week for 15 min per session at times that convenient to their schedules, promptly fill out and return the MASQ

questionnaire to their RSS at each week and use the handheld biofeedback device at their discretion. The emWave PC 1.0 software employed in this study did not include the video clips used in the pilot introductory session. Therefore, we authored a 15-min PowerPoint presentation that outlined basic stress biology, contrasted life threatening and psychosocial stressors, acute vs. chronic stress, and provided HeartMath's explanation of the science behind their biofeedback method.

Quick Coherence technique instructions were presented using display screens from the emWave CD. Then the instructions were repeated with a real-time demonstration of the emWave PC 1.0 software. The emWave computer interface was displayed on a large screen with an RSS hooked up to an ear sensor. The RSS followed the instructions for the Quick Coherence as they were read aloud by the instructor. Participants were thus able to see the effect of the Quick Coherence technique on the Heart Rhythm graph, Coherence Bar Chart and Accumulated Coherence Score. At the conclusion of the demonstration, participants were introduced to their RSS who provided them with contact information and a tour of the lab facilities. Group A participants also made appointments to meet with their RSS at the laboratory for one-on-one training on use of the emWave PC.

In the training session, participants received instruction in use of the finger or ear sensor and starting, running and saving their biofeedback sessions. RSSs also explained the on-screen biofeedback panels and challenge levels and reviewed the Quick Coherence technique. Once the participant felt comfortable with the computer and software she/he was left to complete the first biofeedback session. Each participant was given a key to the computer lab and the access hours were reviewed. In addition, participants were trained in the use of the hand-held emWave Personal Stress Reliever.

The week following orientation and training, Group A began their Heartmath biofeedback program. Participants in both groups filled out two MASQ subscales (AA and GDA) at the end of each week for the next 4 weeks, returning them electronically to their RSS. This phase of the study concluded just before the university's spring break. The participants in Group A completed an exit interview, indicating their experiences and levels of satisfaction with the program. The week following spring break, Group B participants scheduled a meeting with their assigned RSS for a one-on-one training session and received a room key and hand-held emWave device. The next week Group B started the biofeedback program. Both groups continued to fill out the weekly administrations of the MASQ subscales. Hand-held use was monitored for both groups with a question on the weekly MASQ asking about daily usage, i.e., number of times used and duration of use.

Over the course of the study 11 of 35 participants completed all 20 of their desktop biofeedback sessions. The average number of desktop sessions completed was 17.5 (SD = 0.99). The average number of desktop biofeedback sessions completed each week was as follows: week 1, 4.4 (SD = 1.02); week 2, 4.5 (SD = 0.85); week 3, 4.3 (SD = 0.99); week 4, 4.3 (SD = 0.98). Use of the handheld biofeedback device varied considerably with approximately 25% ($n = 8$) not using the handheld device at all and one participant reporting 80 min in a week. The average number of minutes per week that participants used the handheld device was 10.5 (SD = 16). Participants used the handheld devices the most during week 1 (20.4 min, SD = 23.9) and the usage dropped off after that (Week 2 M = 9.5, SD = 18.8; week 3 M = 6.1, SD = 13.8; Week 4, M = 6.0, SD = 18.0).

Data Analysis

Attrition

Because 35 out of 45 students completed the study, it was important to evaluate attrition as a potential threat (i.e., selection bias) to the internal validity of the study (Shadish et al. 2002). Specifically, week one total MASQ (AA/GDA) responses of study completers were compared with responses of noncompleters. Week one total MASQ scores (AA/GDA) for noncompleters were higher on average than completer scores. However, the range of scores for completers (range = 44–97) included proportionately as many participants scoring on the high end of the range as noncompleters (range = 54–97). Additionally, there were no clear patterns of systematic differences in SPWB for noncompleters in comparison to study completers.

Missing Data

It was also important to evaluate whether missing data for study completers were missing *completely* at random, missing at random, or whether there were systematic patterns of missingness (Allison 2002). A thorough analysis was conducted by creating a code for each variable indicating whether or not the participant was missing data on the variable (1 = data and 0 = missing data). A series of t-tests and measures of effect size (Cohen's *d)* were computed to evaluate group differences in MASQ scores for those missing versus not missing data on the preceding variable, and resulted in no identifiable patterns of systematic missingness. In addition, a comparison of scores of those with all complete data (i.e., the data set that would be

used with list-wise deletion) with all available data of those without a complete set of data, via *t* test and Cohen's *d* effect size, did not reveal systematic patterns of missing data. There were four participants, however, who were missing data either the week before or after Spring break. Consequently, although not considered *completely* missing at random, the data were determined to be missing at random (Allison 2002).

Coherence Values

Coherence values were calculated for each participant session in 5-min intervals by Mike Atkinson of HeartMath LLC and he provided the following explanation of that process. The linearly interpolated inter-beat-interval (IBI) time series was raveled into 50% overlapping 64 s segments. The coherence ratio was calculated for each segment separately by first demeaning and de-trending each IBI segment. This was accomplished by subtracting the linear regression (least squares method) line from the IBI segment. Next a hanning widow was applied and the Power Spectral Density (PSD) calculated. Coherence ratio values were calculated as follows: Peak Power/(Total Power − Peak Power). The coherence peak power was identified by locating the tallest peak with in the 0.04–0.26 Hz region of the power spectrum, peak power is calculated by integrating the power in a ±0.015 Hz wide window around the PSD coherence peak. Total power is determined by integrating the in entire PSD region from 0 to 0.4 Hz. The coherence ratio for each 64 s segment was averaged together to form the Coherence Ratio for the data series under analysis, the last partial length segment is not included in the average, in this case the original series was 5 min long and consisted of 8 full length 50% overlapping 64-s segments in the average. The resulting coherence values were natural log transformed for use in statistical analysis because the natural log adjusts proportional variables, such as the coherence values, closer to a normal distribution (Hair et al. 1998).

Study 2 Results

Our first set of research questions in this study centered on the extent to which the results from the pilot study would be replicated. Specifically, we first wanted to examine whether individuals in both groups would show a decline in self-reported symptoms of anxiety and depressed mood while they were participating in the HeartMath biofeedback intervention, as was the case with the pilot.

To address the first set of research questions, we conducted a 2 (immediate v. delay) × 2 (pre vs. post) repeated measures ANOVA on the six MASQ subscales. Significant differences were observed across time for four of the six MASQ subscales, specifically GDM, F (1, 28) = 15.74, $p < 0.001$, GDA, F (1, 28) = 16.33, $p < 0.001$, AA, F (1, 28) = 10.17, $p = 0.003$, LOI, F (1, 28) = 10.83, $p = 0.003$. No significant changes were found over time for GDD or HPA. Table 2 provides the pre and post test means for both groups on each of the six MASQ subscales. As shown, the changes were in the expected direction.

The ANOVA also allowed us to see if the two groups were comparable and to analyze interaction effects to determine if the two groups changed over time in a comparable way. There were no significant interactive effects, indicating, as anticipated, no significant differences in the way the groups responded to the intervention. However, there was a main effect for group for GDA F (1, 28) = 7.07, $p = 0.013$, and AA F (1, 28) = 10.38, $p = 0.003$, indicating that Group A's scores were significantly higher on both of these measures than Group B. There are two likely reasons for this. First, one participant with extremely high anxiety had explicitly requested to transfer from Group B to Group A. A second possible cause for the difference was the delay between entering the study and taking the pre-intervention measures, with the hypothesis being that participants signed up for the study at the relative height of their symptoms.

Analyses of Well-Being Scales

Given that the intervention seemed to have an impact on the mood and anxiety levels in the individuals in the pilot and that the HeartMath LLC company claims that the product will improve one's overall well-being, a second set of research questions pertained to the impact of the intervention on well-being. Two (group) by two (pre-post) repeated measures ANOVAs were performed on the six subscales of the SPWB (Autonomy; Positive Relations with Others; Self-Acceptance; Environmental Mastery; Purpose in Life; and Personal Growth), to examine the

Table 2 Pre-post comparisons of MASQ subscales by group

	Group A ($N = 16$)					Group B ($N = 14$)				
	Pre	Post	Mean Difs.	*t*	Sig.	Pre	Post	Mean Difs.	*t*	Sig.
GDM	46.4	41.2	5.19	2.74	.015	42.8	36.9	5.85	2.86	.013
GDA	32.0	26.5	5.44	2.83	.013	24.9	20.9	3.92	3.42	.004
AA	38.9	32.9	5.94	2.64	.018	28.4	26.0	2.42	2.17	.049
LOI	21.4	18.4	3.00	3.35	.004	22.6	20.0	2.57	1.71	.109
GDD	31.6	30.9	.75	.28	.779	29.5	26.3	3.21	1.41	.180
HPA	69.1	67.5	1.63	.49	.626	57.2	60.6	−3.42	−1.30	.214

MASQ Mood and anxiety symptom questionnaire, *GDM* General distress-mixed, *GDD* General distressed-depressed, *GDA* General distress anxiety, *LOI* Loss of interest, *HPA* High positive affect, *AA* anxious arousal

pre-post change within groups over time, between the two groups, and whether or not there was an interaction (e.g., whether one group changed differentially across time, controlling for the other group) on each of the individual SPWB subscales. Despite the fact that multiple analyses were performed, a liberal alpha level (0.05) was adopted because of the small sample sizes. None of the tests were significant, the effect sizes were extremely small, and examination of the mean scores indicated virtually no change on any of these subscales, suggesting no meaningful differences across time, between the groups, as well as no meaningful interaction effect. Thus, it appears the intervention as administered had no impact on the general domains of well-being measured by the SPWB.

Analyses of HRV Coherence Data

Our third set of research questions centered on the relationship between coherence values and anxiety. Coherence values were computed for all 5-min intervals for each participant session. Given that self-report levels of anxiety diminished for participants in the pilot and the cross-over study, we expected that coherence values would rise as anxiety decreased over the 4 weeks of biofeedback practice in both cross-over groups.

The average first to fourth week difference in HRV (ln) coherence was examined for each group. There were no significant differences in the average first to fourth week coherence, with the exception of a significant difference in average 5-min coherence for Group B, t (15) = 2.423, $p = 0.028$, $d = 0.61$, raw mean difference = 0.288. (This differs slightly from the raw mean difference, above, because of deletion of missing data.) Congruent with the statistical significance testing, Cohen's d for repeated measures were small to negligible for all except the Group B 5-min average.

Correlations between weekly coherence and self-report GDA and AA averages were all nonsignificant except for a negative relationship ($r = -0.608$) between AA and 15-min coherence in week 4 for Group B (Table 3). In addition, several of the other Group B correlations, although nonsignficant, were negative, the direction hoped for, and moderate. However, no such pattern was evident in Group A.

We also explored a secondary question regarding the duration of individual biofeedback sessions. The recommendation on the emWave PC 1.0 CD is for participants to practice the Quick Coherence technique 5–15 min each day. As noted in the introduction, three early studies of the Freeze-Frame technique without biofeedback used 5-min sessions. Thus we wanted to determine if there is a difference in coherence values between the first 5-min interval and the average of the three 5-min intervals making up 15-min session.

Table 3 Correlations between HRV coherence and self-report MASQ weekly measures

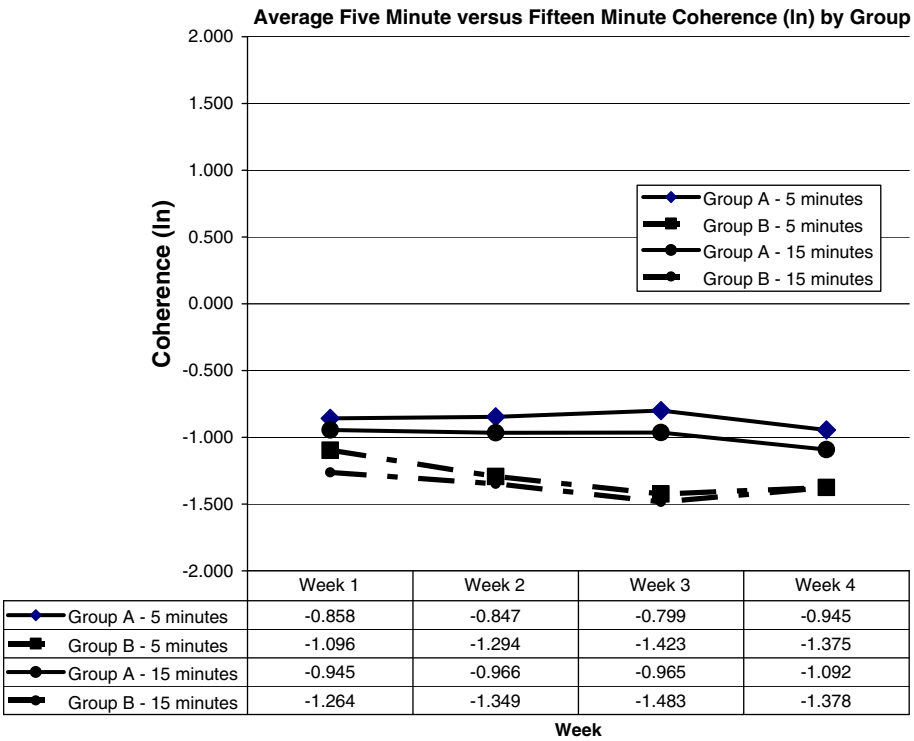
Week 1	Group A ($n = 14$)		Group B ($n = 12$)	
	WK1GDA	WK1AA	WK5GDA	WK5AA
5 min	0.163	−0.184	−0.300	−0.384
15 min	0.014	−0.075	−0.306	−0.173
Week 2	Group A ($n = 14$)		Group B ($n = 12$)	
	WK2GDA	WK2AA	WK6GDA	WK6AA
5 min	−0.013	−0.197	−0.174	−0.284
15 min	0.027	−0.132	−0.365	−0.428
Week 3	Group A ($n = 15$)		Group B ($n = 12$)	
	WK3GDA	WK3AA	WK7GDA	WK7AA
5 min	0.080	−0.029	0.067	−0.066
15 min	0.165	0.128	−0.001	−0.260
Week 4	Group A ($n = 15$)		Group B ($n = 12$)	
	WK4GDA	WK4AA	WK8GDA	WK8AA
5 min	−0.154	−0.244	−0.220	−0.397
15 min	0.002	0.027	−0.367	−0.608*

HRV Heart Rate Variability, *GDA* General distress anxiety, *AA* Anxious arousal

* $p < 0.05$

Figure 1 displays the average 5- and 15-min coherence values for Group A and B over the 4 weeks of their respective biofeedback interventions. In Group A average weekly coherence values varied little over the first 3 weeks and then dropped in the fourth week. Five-minute values were slightly higher than 15-min values, a pattern repeated in Group B. In Group B, coherence values declined in the second and third weeks and then increased slightly in week four. Overall, Group A five and 15-min coherence values were higher than Group B's values for all 4 weeks.

In sum, our expectation of a strong relationship between coherence values and self-report anxiety measures was not met. Coherence values did not trend positive over the course of the interventions and the expected negative correlations between coherence and self-reported anxiety levels appeared weakly in Group B and not at all in Group A. As for the question of biofeedback session duration, the average 5-min coherence values were consistently higher than the 15-min values in both groups but the two sets of values were very close and followed the same pattern over time. These results suggest that 5-min sessions may be just as effective as 15-min sessions for cultivating heart rhythm coherence.



	Week 1	Week 2	Week 3	Week 4
Group A - 5 minutes	-0.858	-0.847	-0.799	-0.945
Group B - 5 minutes	-1.096	-1.294	-1.423	-1.375
Group A - 15 minutes	-0.945	-0.966	-0.965	-1.092
Group B - 15 minutes	-1.264	-1.349	-1.483	-1.378

Fig. 1 Average heart rate coherence (ln) for first 5 min of each session and for 15 min session by group over the 4 weeks of each group's biofeedback intervention

Study 2: Discussion

Because of the success of the pilot study, we ran a larger study and employed an immediate versus delayed treatment design, which both allowed for between group comparisons and ensured that each participant would receive the intervention. The study generally replicated the results of the pilot, although the observed changes were not quite as substantial.

Repeated ANOVAs found significant pre-post differences for four of the six MASQ subscales, specifically GDM, GDA, AA, and LOI. No significant changes were found over time for GDD or HPA. Thus, for each of the three trials, individuals in the intervention showed significant decreases in each of the subscales that measure some facet of anxiety. In contrast, none of the pre-post comparisons of the groups of individuals taking the measures but not the intervention (Group B during Phase A and Group A during Phase B) were found to be significant, except for a significant decrease in HPA was found for Group B.

The consistency of these results suggests that the biofeedback program does reduce levels of anxiety. However, unlike the claims of the manufacturer, there was only some evidence that the program impacted depressed mood, but the results were not consistent. Moreover, there was no evidence that the program increased positive mood or general domains of well-being.

A second goal of the immediate versus delayed study was to determine whether there was a relationship between heart rhythm or psychophysiological coherence and levels of anxiety and negative mood, as claimed by HeartMath. That is, does coherence, as measured by HeartMath, rise as anxiety declines? We found that heart rhythm coherence did not increase over the 4 weeks in either group. Instead, average weekly coherence values either remained steady or declined. Given that the biofeedback appeared effective in reducing anxiety, the lack of correlation between coherence and anxiety suggests either the HeartMath measure of coherence is not capturing the effect of the biofeedback or the HeartMath theoretical understanding of the biofeedback dynamic is incorrect. At the very least the relationship is more complicated than suggested by the authors.

Although the immediate versus delayed treatment design offered a substantially better design for analyzing the effectiveness of the biofeedback program, there were nevertheless several limitations. First, we had some difficulty in recruitment which, combined with attrition and missing data points on some subjects, resulted in the second study also being limited by a relatively small sample size. Additional limitations pertain to the generalizability of the results, as the sample was selected from a large group of possible participants. In a related vein, the individuals in the study were selected based on scores on a self-report measure and were not identified as having a diagnosable anxiety disorder, thus questions remain regarding

the extent to which individuals who suffer from diagnosable anxiety disorders would respond to the intervention, and that there might be important differences in the effectiveness of the intervention between individuals who participated in the study and those who simply purchase the product and utilize it on their own. Finally, because we found no reliable relationship between the self-reported levels of anxiety and psychophysiological coherence, the current study raises more questions about those processes than it answers about the relationship between psychophysiological coherence and anxiety.

General Discussion

Epidemiological studies indicate levels of anxiety and the prevalence of anxiety disorders are increasing. The current economic downturn that began in 2008 and substantial uncertainty about the global state of affairs on numerous fronts will likely be accompanied by even greater levels of stress and anxiety in the near future. Currently, psychotherapy and pharmacotherapy are the two primary forms of treatment for heightened anxiety. Unfortunately, both are expensive and require highly trained professionals to administer. Moreover, the former is time consuming and the latter is associated with significant side effects. If a relatively cheap and effective method for reducing anxiety in the general population could be found, the benefits could be enormous.

Toward that end, we examined the effectiveness of a computer-based biofeedback system in reducing anxiety in college students in two separate studies, and found a replicable result that the intervention reduced levels of anxiety. Although these studies were somewhat limited by small sample sizes, the result is nonetheless worthy of attention because of the practical significance this kind of intervention affords. The program is available to the general public and can be loaded on virtually any personal computer, making it potentially widely accessible. Individuals can purchase and use the system, and it is easy to envision, for example, hospitals, mental health clinics and college counseling centers setting up a space for computer based biofeedback for clients with anxiety related problems and encouraging clients to participate as a supplement with current treatments.

There are a number of directions opened up by this research. The first would be to replicate the results with a larger study. If successful, then research needs to establish the generalizability of these results in other populations, such as the general adult population, adolescents, and individuals with diagnosable anxiety problems. Second, explorations are needed regarding the mechanisms of impact. Most obviously, additional research is needed examining the relationship between psychophysiological coherence and self-reported levels of anxiety and mood. Additional research dismantling the causal variables underlying the reduction in anxiety is also warranted. For example, is the biofeedback signal crucial, the time spent focused on positive emotions, or is the effect primarily a consequence of paced breathing? Finally, research needs to be done on whether similar results would be found with individuals employing the technique on their own (i.e., in their own homes, on their own computers, with little input from researchers). If so, such programs as the one explored here could become a significant and important tool in alleviating the increasing burden of anxiety in our culture.

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References

Allison, P. D. (2002). *Missing data. (Sage University Papers Series on Quantitative Applications in the Social Sciences, series no. 07–136)*. Thousand Oaks, CA: Sage.

American College Health Association National College Health Assessment Spring. (2006). Reference group data report (abridged). (January/February 2007). *Journal of American College Health, 55*(4), 195–206.

Bradley, R. T., McCraty, R., Atkinson, M., Arguelles, L., Rees, R. A., & Tomasino, D. (2007). *Reducing test anxiety and improving test performance in America's schools: results from the TestEdge national demonstration study*. Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Report no. 07–04-01.

Cohen, H., Matar, M. A., Kaplan, Z., & Kotler, M. (1999). Power spectral analysis of heart rate variability in psychiatry. *Psychotherapy and Psychosomatics, 68*, 59–66.

Friedman, B. H. (2007). An autonomic flexibility-neurovisceral integration model of anxiety and cardiac vagal tone. *Biological Psychology, 74*(2), 185–199.

Giardino, H. D., Chan, L., & Borson, S. (2004). Combined heart rate variability and pulse oximetry biofeedback for chronic obstructive pulmonary disease: Preliminary findings. *Applied Psychophysiology and Biofeedback, 29*, 121–133.

Hair, J. F., Andersen, R. E., Tatham, R. L., & Black, W. C. (1998). *Multivariate data analysis*. Englewood Cliffs, NJ: Prentice Hall.

Hassett, A. L., Radvanski, D. C., Vaschillo, E. G., Vaschillo, B., Sigal, L. H., Karavidas, M. K., et al. (2007). A pilot study of the efficacy of heart rate variability (HRV) biofeedback in patients with fibromyalgia. *Applied Psychophysiology and Biofeedback, 32*, 1–10.

Karavidas, M. (2005). Heart rate variability biofeedback in the treatment of major depressive disorder. *Applied Psychophysiology and Biofeedback, 30*, 397–423.

Lehrer, P. M., Vaschillo, E., Vaschillo, B., Lu, S.-E., Eckberg, D. L., Edelberg, R., et al. (2003). Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. *Psychosomatic Medicine, 65*, 796–805.

McCraty, R., Atkinson, M., & Lipsenthal, L. (2000). *Emotional self-regulation program enhances psychological health and quality of life in patients with diabetes*. Boulder Creek, CA: HeartMath Research Center, Institute of HeartMath. Publication No. 00–006.

McCraty, R., Atkinson, M., & Tomasino, D. (2003). Impact of a workplace stress reduction program on blood pressure and emotional health in hypertensive employees. *Journal of Alternative and Complementary Medicine, 9*, 355–359.

McCraty, R., Atkinson, M., Tomasino, D., & Bradley, R. T. (2006). The coherent heart: heart-brain interactions, psychophysiological coherence, and the emergence of system-wide order. *HeartMath Research Center, Institute of HeartMath*, Publication No. 06-022, Boulder Creek, CA. 64 pages.

Reger, M. A., & Gahm, G. A. (2009). A meta-analysis of the effects of internet- and computer-based cognitive-behavioral treatments for anxiety. *Journal of Clinical Psychology, 65*, 53–75.

Reiner, R. (2008). Integrating a portable biofeedback device into clinical practice for patients with anxiety disorders: Results of a pilot study. *Applied Psychophysiology and Biofeedback, 33*, 55–61.

Ryff, C. D. (1989). Happiness is everything, or is it? Explorations on the meaning of psychological well-being. *Journal of Personality and Social Psychology, 57*, 1069–1081.

Ryff, C. D., & Keyes, L. M. (1995). The structure of psychological well-being revisited. *Journal of Personality and Social Psychology, 69*(4), 719–727.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. New York: Houghton Mifflin Company.

Spielberger, C. D. (1970). *Manual for the state-trait anxiety inventory*. Palo Alto, CA: Consulting Psychologists Press.

Stein, P. K., & Kleiger, R. E. (1999). Insights from the study of heart rate variability. *Annual Review of Medicine, 50*, 249–261.

Task Force of the European Society of Cardiology, & The North American Society of Pacing Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation, 93*, 1043–1065.

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience and Biobehavioral Reviews, 33*, 81–88.

Thayer, J. F., & Sternberg, E. M. (2006). Beyond heart rate variability: Vagal regulation of allostatic systems. *Annals of the New York Academy of Sciences, 1088*, 361–372.

Tiller, W. A., McCraty, R., & Atkinson, M. (1996). Cardiac coherence: A new, noninvasive measure of autonomic nervous system order. *Alternative Therapies, 2*, 52–65.

Twenge, J. M. (2000). The age of anxiety? Birth cohort change in anxiety and neuroticism, 1952–1993. *Journal of Personality and Social Psychology, 79*, 1007–1021.

Watson, D., & Clark, L. (1991). The Mood and Anxiety Symptom Questionnaire. Unpublished Manuscript.

Watson, D., Weber, K., Assenheimer, J. M., Clark, L., Strauss, M. E., & McCormick, R. A. (1995). Testing a tripartite model: I. Evaluating the convergent and discriminant validity of anxiety and depression symptom scales. *Journal of Abnormal Psychology, 104*, 3–14.

Zetterqvist, K., Maanmies, J., Strom, L., & Andersson, G. (2003). Randomized controlled trial of internet-based stress management. *Cognitive Behaviour Therapy, 32*(3), 151–160.