Biofeedback
Volume 41, Issue 3, pp. 98–109
DOI: 10.5298/1081-5937-41.3.08

SPECIAL ISSUE

Protocol for Heart Rate Variability Biofeedback Training

Paul Lehrer,[1] Bronya Vaschillo,[2] Terri Zucker,[3] Jessica Graves,[4] Maria Katsamanis,[1] Milisyaris Aviles,[1] Frederick Wamboldt[4]

[1]Robert Wood Johnson Medical School and [2]Center for Alcohol Studies, Rutgers, The State University of New Jersey, Piscataway, NJ; [3]Private Practice, San Mateo, CA; [4]National Jewish Health, Denver, CO

Keywords: resonance, applied psychophysiology, biofeedback, short-term therapy

This paper describes a five-visit heart rate variability (HRV) biofeedback protocol we have used both clinically and in research. This protocol was refined in a study of biofeedback therapy for treating asthma. Similar, longer methods have been used for treating various conditions involving pain, anxiety, depression, and other psychophysiological disorders.

This paper presents our heart rate variability (HRV) biofeedback protocol as we have been using it in our recent research. It is a modification of a 10-session procedure we have described previously (Lehrer, Vaschillo, & Vaschillo, 2000). We describe here a five-visit protocol based on our current research experience. In previous research we have used longer protocols, but have found that the technique usually can be taught in fewer visits (Vaschillo, Vaschillo, & Lehrer, 2006). We have used similar protocols for treating asthma (Lehrer et al., 2004), for which these protocols were developed, as well as depression (Karavidas et al., 2007), fibromyalgia (Hassett et al., 2007), multiple unexplained somatic symptoms (Katsamanis et al., 2011), and experimental investigation of biofeedback effects (Lehrer et al., 2010; Lehrer et al., 2003).

A description of the HRV biofeedback method, its rationale, and its clinical effects have been reviewed elsewhere (Lehrer, 2007, 2013; Vaschillo et al., 2006). Briefly, the technique involves learning to breathe at a resonance frequency of the cardiovascular system. At this frequency, respiratory effects on heart rate stimulate baroreflex effects, such that both respiratory sinus arrhythmia and baroreflex gain are maximized. Also, breathing at this frequency causes heart rate to go up and down in phase with respiration (heart rate increases with inhalation, decreases with exhalation) and respiratory gas exchange efficiency is maximized (Vaschillo, Vaschillo, & Lehrer, 2004; Yasuma & Hayano, 2004). Regular practice of this technique over a period of time has been shown to produce clinically significant improvement for a variety of disorders, including pain (Hallman, Olsson, von Scheele, Melin, & Lyskov, 2011), asthma (Lehrer et al., 2004), anxiety (Henriques, Keffer, Abrahamson, & Horst, 2011), depression (Karavidas et al., 2007; Siepmann, Aykac, Unterdorfer, Petrowski, & Mueck-Weymann, 2008), chronic obstructive pulmonary disease (Giardino, Chan, Borson, & Biofeedback, 2004), food cravings (Meule, Freund, Skirde, Vogele, & Kubler, 2012), and hypertension (Lin et al., 2012; Reineke, 2008).

Manual for HRV Biofeedback Training

Visit 1

Introductory instructions.

1. We use the following instructions the first time we attach sensors to the client to assess baseline. This is part of our research protocol and is often omitted in clinical practice. Instructions: "*Today, I am going to introduce you to a method that will help you control your symptoms. We will be using a number of measuring devices, and wearing them may feel a little strange in the beginning. This introduction will allow you to become familiar with what it feels like to wear the sensors, and to watch the body signals they are measuring on the screen, before we start your biofeedback training. I will attach all of the sensors to your body and then you will see what they are measuring on your monitor. These sensors will simply be measuring your physiological activity and will not cause any harm to you. I will briefly explain what each measurement is.*"
2. Attach sensors that will be used. Check impedances and signal test. Begin display of physiological data.
3. Explain what each graph or number represents on the screen. The exact description may differ, depending on the particular hardware and software used and the particular array of physiological measures. Exact instructions will depend on the hardware/software

configuration. "*In this top graph, the red line is your heart rate in terms of beats per minute, and the blue line shows your breathing. You'll notice that the blue line moves up as you breathe in and down as you breathe out.*" Give very brief answers to any questions asked.

4. Resonance frequency determination. Paraphrase the following explanation to the client:
   a. People are able to produce very large increases in HRV through biofeedback because of "resonance" characteristics in the cardiovascular system. Actually, this system resonates the same way that a musical instrument does. HRV biofeedback stimulates a particular reflex in the cardiovascular system that has a certain rhythm to it. It is called the "baroreflex" and it helps to control blood pressure. It also helps to control emotional reactivity and promotes breathing efficiency. When blood pressure goes up, the baroreflex causes heart rate to go down, and when blood pressure goes down, heart rate goes up. This causes a rhythm in heart rate fluctuations. When a person breathes at this exact rhythm (which varies among people, generally between 4.5 and 6.5 times a minute), the system resonates, much like the sound of a vibrating string resonates in the box of a violin, creating a big sound. We have written about this process elsewhere in some detail (Lehrer, 2013; Vaschillo et al., 2006). This section of the procedure is devoted to finding the frequency for each person at which the baroreflex system resonates. This will be the frequency that produces the biggest swings in heart rate between inhaling and exhaling. When people breathe at this frequency, the baroreflex system is stimulated and strengthened (Lehrer et al., 2003), and through projections to other systems in the body (e.g., inflammatory and limbic systems), other events occur that produce the many beneficial effects of HRV biofeedback.
   b. Resonance frequency determination is sometimes done in the first visit, sometimes in a subsequent visit. For recording data, use a form similar to Figure 1. All relevant parameters may not be available in any particular hardware/software system. Include parameters that can be measured. Optimally, it is desirable that the system provide instantaneous information on heart rate, respiration, average low-frequency (LF) heart rate oscillations (0.05–0.15 Hz), and a running spectral chart showing average amplitude of heart rate fluctuations at each frequency. The following instructions assume a screen showing heart rate (or interbeat interval) and a changing spectral analysis of interbeat interval, updated frequently (usually every second or two, calculating the frequency curve looking back approximately 30–60 seconds). If a respiratory tracing also is desirable, the phase relationship between HRV and respiration can be observed. Using both thoracic and abdominal sensors will allow assessment of changes in thoracic versus abdominal components in breathing. Some software programs also provide a continual average of low-frequency (LF) HRV (~0.05–0.1 Hz).
   c. Connect the client to the biofeedback instrumentation. Explain about resonance frequency, why it is important, and how we will find it.
5. "*Today we are going to find out the speed of breathing that should best help you to cope with your symptoms. This breathing frequency is different for each person. When you breathe at this rate, your breathing will produce strong effects on your nervous and cardiovascular systems that should be very good for you, and should help you to control your symptoms.*"
6. "*Your heart rate varies with each breath, and with various other processes in your body, including the baroreflex. This variability is good and is a sign of health. We will now find your "resonance frequency"—the speed of breathing at which your HRV is the highest. In this task, we will ask you to breathe at five rates for periods of about two minutes each. You should not find this task difficult. However, if you feel uncomfortable at any time, you can simply stop the task and tell us. When we begin, we will ask you to breathe in and out at a 10-second breathing rate. Then we will ask you to breathe at various other rates, so we can find the exact frequency at which your cardiovascular system resonates. This will be your own resonance breathing frequency. You will be able to use this breathing rate to best help your symptoms. Breathe easily and comfortably, but not too deeply. Do not try too hard. Do you have any questions?*"
   a. Begin by pacing breathing at 5.5 or 6 times a minute for several minutes.Coach the client to breathe with the pacing stimulus, as evenly as possible. This rate of breathing is at the average resonance frequency of the cardiovascular system for adults. If the individ-

BPM Pace	Task Duration	LF Power	LF Spectral peak-Y axis	Spectral Distribution*	Peak-Valley Difference (HR MaxMin)	Phase Relationship of Heart Rate vs. Respiration Rate	Client Comfort Level & Comments

*Under “spectral distribution,” describe the ”internal coherence (HeartMath)“ or amount of spectral variance explained by the respiratory frequency. A statistic yielding information that is similar to “internal coherence” is “normalized LF HRV,” a statistic that many programs display. The “normalized” value is variously calculated as LF / (LF + HF) or LF / (VLF + LF + HF).

Figure 1. Recording sheet for determining resonance frequency.

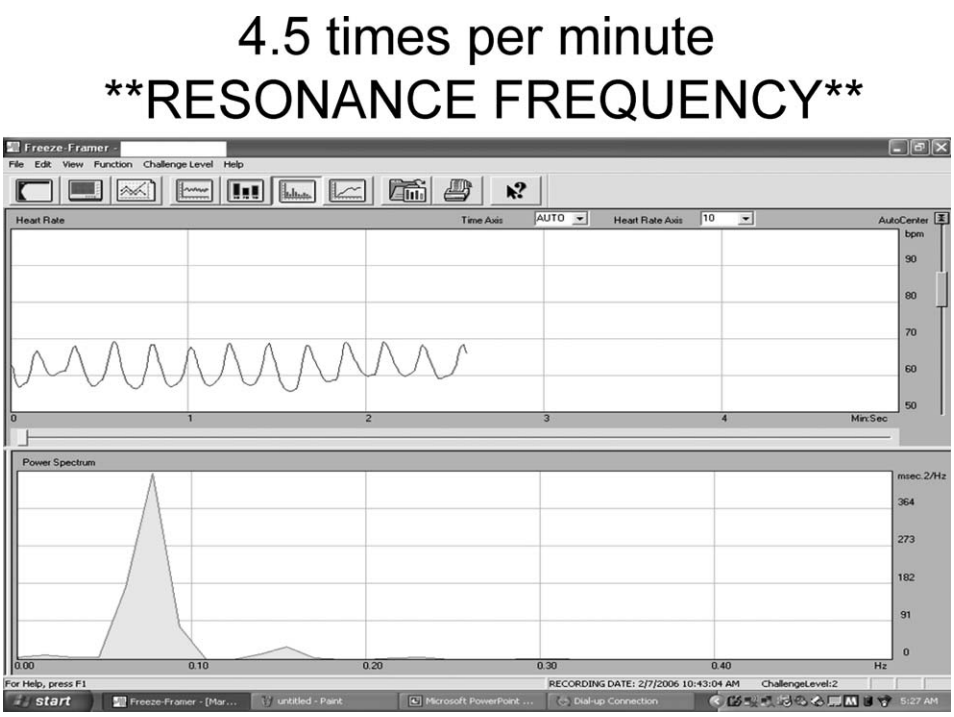


Figure 2. Spectral distribution of HRV when breathing at resonance frequency.

ual feels uncomfortable breathing at this rate, choose one that is slightly faster or slower.

b. Ask about hyperventilation symptoms (primarily lightheadedness, dizziness, heart pounding) and instruct the client to breathe less deeply if needed. Record observations, particularly if and when measures of LF HRV and the amplitude of the LF peak in a frequency spectrum become stable. This will happen in approximately one minute. Record respiration rate if a respiratory sensor is attached.

c. After the client is breathing regularly at this frequency, and the spectral LF peak and LF HRV values become stable, record the values on the Resonance Frequency Worksheet (Figure 1). After each frequency, pause and tell the client to relax, and stop doing paced breathing for a minute or two (or until client is relaxed and ready to start new task). Ask the client how it felt.

d. Repeat this procedure as the individual does paced breathing at each of the following frequencies: 6.5, 5.5, 5, and 4.5 times per minute. Allow the client to rest for a few minutes between each respiratory frequency, and ask the client about comfort or discomfort, hyperventilation symptoms, etc. Repeat the procedure at slower or faster frequencies if the highest spectral peak is at 4.5 or 6.5, respectively. Before breathing at each frequency, say, "*Now try breathing at this frequency (following the pacer).*"

e. Record each of the following variables on the record chart (Figure 1). Some software configurations may not have all these parameters. Record as many as possible.

   i. Phase convergence with breathing: Does heart rate go up just as the client is inhaling and down just as the client is exhaling, or are heart rate and breathing somewhat out of phase? Estimate the degree to which they are out of phase (0° = in phase, 180° = heart rate goes up during exhalation and down during inhalation, 90 degrees = heart rate starts going up in the middle of an inhalation and down in the middle of an exhalation.

   ii. Peak-trough amplitude: Peak heart rate during inhalation minus lowest heart rate during exhalation.

   iii. LF, as an absolute value in ms^2/Hz and as percent total: If your software calculates average frequency power in the low frequency range (approximately 0.05–0.15 Hz), enter this value.

   iv. Maximum LF amplitude peak on the spectral graph in ms^2/Hz. If your program displays a frequency analysis, enter the height of the curve

at the respiratory frequency, which almost always will be the highest peak in the curve.

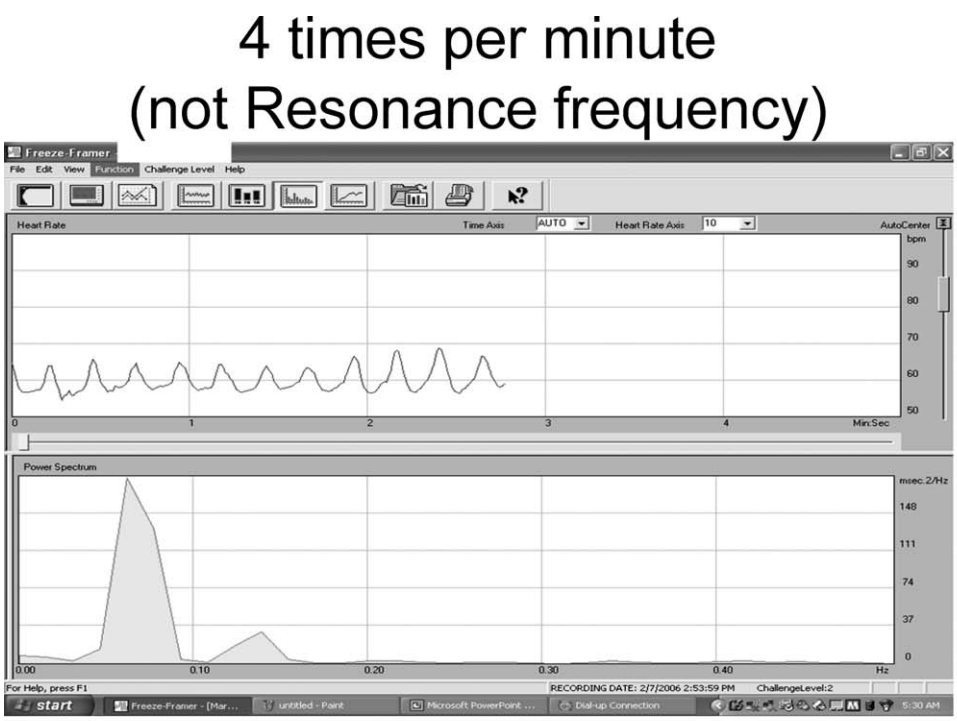
v. Smoothness of the "envelope" of the HR curve: Note whether the heart rate (cardiotachometer) tracing looks like a sine wave or the extent to which it is irregular or jagged.

vi. Singularity and cleanliness of the LF peak in the spectral graph: Is there a single peak in the LF range or are there several peaks? If there are other peaks than at respiratory frequency, are they all much smaller than the respiratory frequency peak?

f. Estimate the resonance frequency from the best convergence of the following characteristics: the best phase convergence with breathing, highest peak-trough amplitude, highest LF, the maximum LF amplitude peak on the spectral graph, a fairly constant "envelope" of the HR curve, and cleanest and highest-amplitude LF peak). Choose the frequency with the greatest density of these measures.

g. Retest any frequency where the client did not breathe at a constant rate.

7. Inform the client of his/her resonance frequency.
8. If the results are not clear, instruct the client to do home breathing exercises at the frequency that appears to have the best characteristics and to let you know at the next visit how it felt. Retest in the next visit.
9. Note: In the first visit, the client's psychological state may change during this procedure, such that amplitudes may increase over time as the individual becomes more relaxed. Thus, it may be difficult to get a reliable estimate of resonance frequency, which is an invariant characteristic of the individual, most closely related to the individual's blood volume (Vaschillo et al., 2006). Sometimes a better estimate can be obtained by repeating some breathing frequencies, although the client might have become fatigued by this time. In a subsequent visit, it is advisable to test breathing at several frequencies, at and adjacent to the resonance frequency determined in this visit, in order to verify that resonance frequency has been correctly determined. Note that the amplitude of HRV may change during a visit because the individual's emotional state may change (e.g., become more relaxed). This may obscure detection of resonance frequency, particularly in the first HRV biofeedback visit.
10. We sometimes have used an additional method, often even in the first visit, although usually in the second or third: biofeedback. After having done some paced breathing maneuvers, as above, instruct the client to breathe with the heart rate signal, to inhale when heart rate goes up and exhale as it goes down, and to try to maximize the peak-to-trough heart rate swings. This should be done without breathing too deeply because that could cause hyperventilation. Then, where possible, measure the individual's respiration rate. This may produce a more accurate estimate of resonance frequency than paced breathing, because the actual resonance frequency probably would not occur at exactly 6, 6.5, etc. breaths per minute, but rather at an odd frequency such as 6.23 breaths per minute.
11. Also note that some individuals find paced breathing to be aversive and difficult, while they may find HRV biofeedback to be easy and comfortable. If this is the case, switch to biofeedback, and find a way for the client to have access to a home trainer unit, many of which are available commercially through the internet, including some mobile phone applications. Various programs for guiding paced breathing also are available online for various computer and mobile devices (e.g., E-Z Air: various computer devices; Stress Doctor, Breathe Together, and Breathe2Relax: iPhone; MyCalmBeat and Paced Breathing: Android; and others that are added frequently in various websites).
12. Figure 2 shows a spectral chart of HRV alone when an individual is breathing at resonance frequency. Figure 3 shows the chart when the individual breathes at other frequencies. Note that the height of the spectral peak at the respiratory frequency is higher when breathing at resonance frequency, and the contrast between oscillations at this frequency is proportionally greater than at other frequencies in the spectrum. Figure 4 shows resonance frequency breathing in a chart containing respiration as well as HRV.
13. Homework after the first training visit: (First calculate the number of seconds per breath for resonance frequency breathing.)
    a. Instruct the individual to practice breathing with the second hand of a watch or a downloaded computer breathing pacer at the resonance frequency for 20 minutes twice a day. Also instruct the client to begin practicing at resonance frequency.
    b. Explain that it will be more beneficial to breathe out longer than in.
    c. Instruct the client to be aware of hyperventilation symptoms and to breathe more shallowly and naturally if they occur.
    d. Explain that heart rate should go smoothly up and down a maximum amount while breathing at the resonance frequency.



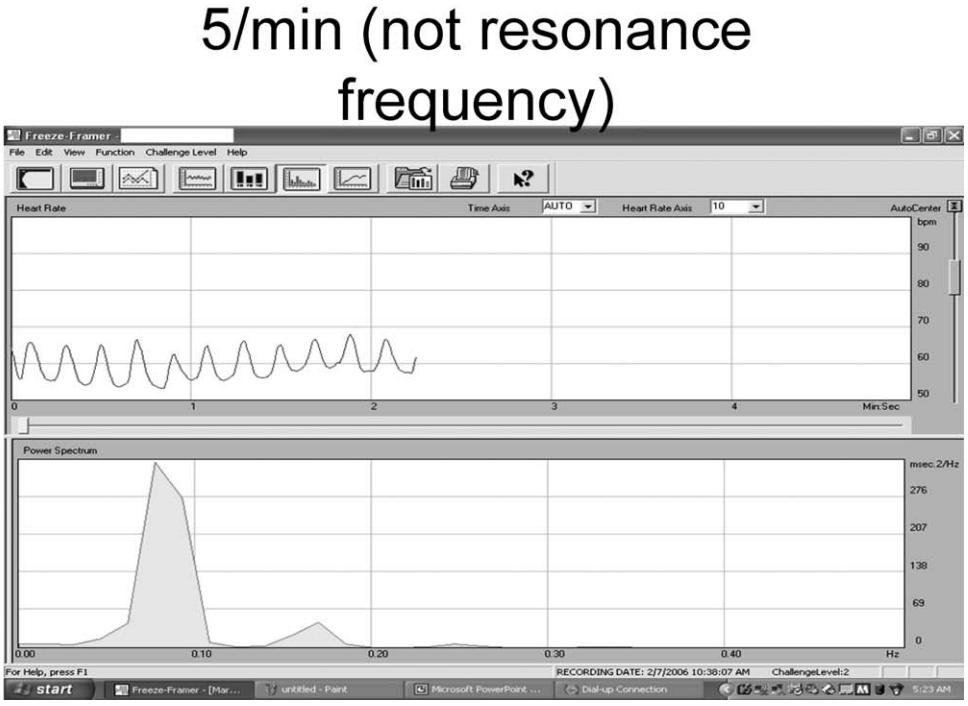


Figure 3. Spectral charts of HRV when individual is doing paced breathing at frequencies close to resonance frequency, but not at the resonance frequency.

e. Instruct the client: "*Breathe easily and comfortably. Do not try too hard.*"

f. Instruct the client about use of the technique: "*We think that practicing biofeedback and/or paced breathing at resonance frequency two times/day for about 20 minutes each time may prevent your symptoms from arising or may decrease their intensity. Please do your best to practice the*

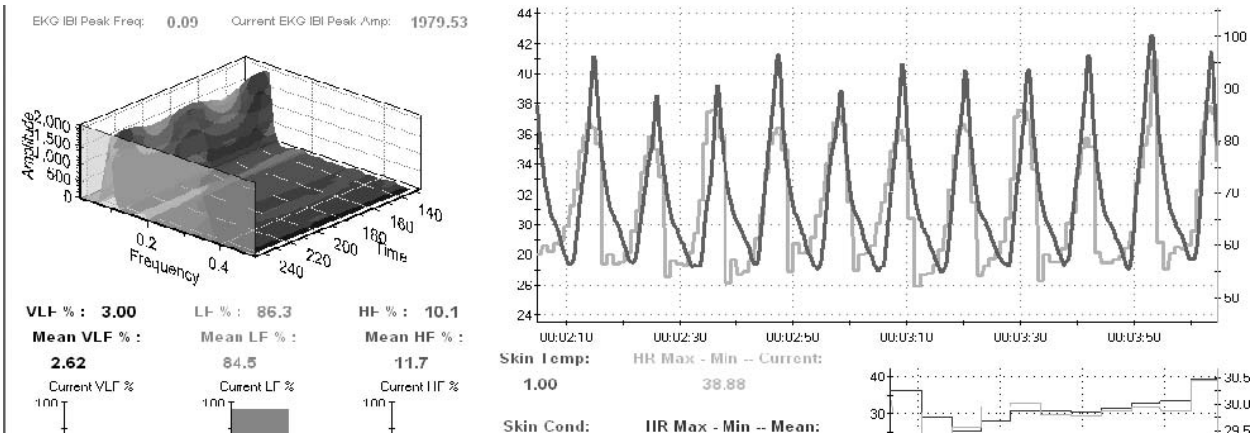


Figure 4. Complex screen showing resonance frequency breathing. There is an in-phase relationship between heart rate and breathing in upper right box. A Fourier transformation (upper left) shows a stable recording over time, with a single peak in the LF range, overshadowing all other sources of variation. The amplitude of the LF peak (in ms^2/Hz) and the dominant oscillation frequency (here shown as 0.09 Hz) are presented digitally above the frequency graph. The bottom right graph shows changes in peak-trough amplitude of oscillations, with digital representation to the left. The bottom left graph shows percent of HRV variance in the high frequency, low frequency, and very low frequency ranges. Almost all of the variance is in the LF range, which contains the respiratory frequency.

technique regularly. We don't know if it will have any immediate effects during symptoms, so regular practice and mastering the technique are very important."

Visit 2

Visit Overview. Practice resonance frequency breathing. Fine tune resonance frequency. Train the client in pursed lips breathing.

1. First, ask how the client is feeling and whether he or she has any questions.
2. Explain about fine-tuning the resonance frequency:
   a. "*Today we are going to fine-tune the speed of breathing that we think will best help you. Again, this pace will be beneficial for you and may help you control your symptoms.*"
3. Attach sensors to the client.
4. Review breathing technique.
   a. Review resonance frequency breathing with longer exhalation than inhalation:
      i. "*First let's review your resonance frequency breathing. Breathe easily and comfortably rather than deeply. Do not try too hard. I will ask you to breathe more shallowly if necessary throughout the visit.*"
   b. Check for symptoms of hyperventilation (lightheadedness, tingling, pounding heart, feelings of breathlessness, dizziness, and/or anxiety) and instruct the individual to breathe more shallowly if they are present.
5. Resonance frequency fine tuning
   a. Have the client do paced breathing at three frequencies: resonance frequency (from the previous visit) for three to five minutes and then half breaths per minute faster and slower. Verify the frequency with characteristics of resonance (highest amplitude of spectral peak, highest LF activity, in-phase heart rate and respiration, smooth spectral peak, and smooth heart rate oscillation).
6. Biofeedback: Teach and practice breathing with pursed lips at resonance frequency (five minutes)
   a. Have the client perform paced breathing for five minutes at resonance frequency.
   b. "*Breathe easily and comfortably rather than deeply. Be sure to breathe out longer than you breathe in. Inhale through your nose; exhale through your mouth with pursed lips as if you were blowing through a straw. This will help to slow down the flow of air as you breathe out and will help you to exhale longer. Try to relax and feel comfortable.*"
7. Abdominal breathing (10-minute maximum). The following explanation may be more than needed; paraphrase where appropriate.
   a. "*We now are going to give you some training in relaxed breathing. Relaxed breathing will enhance the effects of biofeedback. When you are relaxed, your chest and your abdomen relax and you begin to breathe more naturally, so that your abdomen expands when you inhale and contracts (goes back in) when you exhale. Let me show you what I mean.*"
   b. "*Here is how your body breathes abdominally.*" (Show a diagram of respiration, easily found on the

internet, e.g., http://www.womens-health-advice.com/respiratory-system.html, http://www.bbc.co.uk/schools/gcsebitesize/pe/appliedanatomy/1_anatomy_respiratorysys_rev1.shtml).

"*As you can see, when you inhale, air fills the lungs, the diaphragm descends, and the front of the abdomen, the lower back, and the sides of abdomen expand. When you exhale, the diaphragm relaxes and rises and your abdomen goes back in. When you breathe in, your diaphragm moves down and seems to push your abdomen out, so it seems like you are breathing from your abdomen. When your diaphragm moves down, a partial vacuum is created in your lungs, so your lungs fill up. Your lungs don't do anything during breathing. They are passive, like balloons. When the diaphragm goes down, air comes into the lungs from outside to fill the vacuum. Although some small muscle activity also may occur throughout the trunk of your body, most of breathing comes from the diaphragm. The chest doesn't do much in relaxed breathing. If your abdomen is tense, when the diaphragm moves down, it has no place to go because your body is preventing the movement. Then, in order to breathe, you must use extra muscles in the chest and neck. Then you seem to be breathing from your chest. This extra muscle tension increases the work of breathing and may worsen your symptoms.*"

c. Demonstrate abdominal breathing. Point to the position of your diaphragm in your own body.
   i. "*Try to breathe into your abdomen, a few inches below your navel. This will help you breathe in a more relaxed way.*" "*Now let's try abdominal breathing.*"
   ii. Place one hand on your chest and the other on your abdomen, just below your navel.
   iii. "*In relaxed breathing, as I inhale and exhale, the bottom hand moves up and down, and the top hand doesn't move much at all.*"
d. Demonstrate with three inhalations.
   i. "*Do you see that? Now you try it, just to get the feel of it. Relax and place one hand on your chest and the other on your abdomen.*"
e. Continue to model for the client as the client attempts abdominal breathing.
   i. "*Now breathe in through your nose with your mouth closed. Good. And now breathe out through pursed lips, like this. Okay, good. Now breathe so that just your abdomen moves in and out, while your chest stays still. Keep breathing in through your nose and out through pursed lips.*"
f. Let the client try this maneuver a few times while you continue to model. If the client is doing well, compliment him or her, and give instructions to continue breathing this way for five minutes.
g. If the client finds abdominal breathing difficult, give instructions to continue breathing slowly and to stop trying to do abdominal breathing. Say that you will return to it later. Do not spend more than 10 minutes teaching diaphragmatic breathing, because it may be frustrating for some individuals.

8. Homework:
   a. The client should use resonance frequency breathing technique with pursed lips abdominal breathing, using a watch or a downloaded computer breath pacer, 20 minutes two times a day. Instruct the client to practice breathing at the resonance frequency.
   b. The client should practice abdominal breathing for five minutes with hands on the chest and abdomen, in front of a mirror or in a bed.
   c. Remind the client to breathe out longer than in.
   d. Instruct the client to be aware of hyperventilation symptoms and to breathe more shallowly if they occur.
   e. If the client is using a home biofeedback trainer that displays heart rate, the heart rate should go smoothly up and down a maximum amount while breathing at the resonance frequency.
   f. Instruct the client: "*Breathe easily and comfortably. Do not try too hard.*"
   g. Instruct the client about use of the technique: "*We think that practicing biofeedback for 20 minutes, two times/day will stabilize your autonomic nervous system, lungs, blood pressure, and emotion, and prevent your symptoms from arising. Please do your best to practice the technique regularly. We don't know if it will have any immediate effects on symptoms, so regular practice is very important.*"

Visit 3

Visit overview. Return to abdominal breathing if the client was not able to learn it in the previous visit. Briefly practice resonance frequency breathing with a pacer. Perform resonance frequency HRV training without a pacer and use heart rate tracing for biofeedback.

1. First, ask how the client is feeling and whether there are any questions.
2. Connect sensors to the client.
3. Review the breathing technique: Review resonance frequency pursed lips abdominal breathing with longer

exhalation than inhalation and monitor hyperventilation symptoms:

a. "*First let's review resonance frequency breathing. Breathe easily and comfortably rather than deeply. Do not try too hard. Please try to breathe using your diaphragm as we were doing before. Inhale through your nose and try to feel how your abdomen fills up with air like a balloon. Exhale through your mouth, through pursed lips. Breathe out longer than you breathe in. Just concentrate on your abdomen moving out and in as you breathe, try to relax and feel comfortable. Can you feel all sides of your abdomen moving? Can you feel the roundness of your diaphragm more clearly? The breath comes in and out of your body the usual way. But you can feel your body moving differently. You may feel the breath even lower in your body: in your lower back, your pelvis or even your upper legs.*"

b. Do not spend more than five minutes on abdominal breathing. If the client experiences hyperventilation symptoms, give instructions to breathe more shallowly. If the client is doing well, instruct him/her to continue breathing in this way, for two to three minutes at the resonance frequency.

4. Practice abdominal breathing with pursed lips at the resonance frequency (five minutes)
   a. Have the client perform paced pursed lips abdominal breathing for five minutes at the resonance frequency. Watch for hyperventilation symptoms.
5. Have the client take a two-minute break.
6. HRV biofeedback.
   a. Instruct the client to maximize HRV using a cardiotachometer as biofeedback. Instruct the client to do this by breathing in phase with heart rate changes. Remind the client not to breathe too deeply, particularly if experiencing dizziness or lightheadedness.
   b. "*Begin by breathing at your resonance frequency using the pacer. We will do this for a minute or two. Then shift to following your heart rate. Look at this red line (point to the cardiotachometer tracing). When your heart rate goes up, this red line goes up. When it goes down, the line goes down. Breathe in phase with your heart rate. When your heart rate goes up, breathe in. When your heart rate goes down, breathe out. Try to make your heart rate swing up as much as possible when inhaling and down as much as possible when exhaling.*"
   c. Practice and coach the client for two to three minutes, or until the client starts to do the task correctly.
7. HRV biofeedback with pacing stimulus only as needed (five minutes)
   a. Have the client perform HRV paced abdominal pursed lips breathing. "*Breathe into your back as well as your abdomen for five minutes at the resonance frequency.*" Let the client look at the pacer if necessary.
   b. "*Continue to breathe in phase with your heart rate. When your heart rate goes up, inhale. When it goes down, exhale. Make your heart rate go up as far as possible and down as far as possible. Continue breathing out longer than you breathe in. Breathe so that the changes in heart rate with each breath are the biggest. Breathe easily, without tension. Breathe naturally. Don't try too hard. It should just flow almost automatically. Don't think too much about how to do it. Maybe it won't work right away. It will improve with time.*"
   c. *Try to make your heart rate go up and down the most by finding the right breathing rate. Do not breathe more deeply. That would cause hyperventilation.*
   d. The therapist notes the client's respiration rate, the amplitude of HRV, average LF activity, and the LF spectral peak. If the peak and/or average LF diminishes, instruct the client to change the respiration rate up or down to the approximate resonance frequency. The LF peak may be higher than at the previously measured resonance frequency. If so, measure the client's rate of breathing and instruct the client that this will be the new resonance frequency for home practice.
8. HRV biofeedback with abdominal breathing and pursed lips (two to three minutes of practice and one task of five minutes). Have the pacer accessible. Have the client perform paced abdominal back breathing with pursed lips for five minutes at the resonance frequency.
   a. "*Breathe in phase with your heart rate. When your heart rate goes up, inhale. When it goes down, exhale. Make your heart rate go up as far as possible and down as far as possible. Continue breathing out longer than you breathe in. Breathe so that the changes in your heart rate with each breath are the biggest. Breathe easily and comfortably rather than deeply. Please try to breathe using your diaphragm as we were doing before. Breathe into your back. Inhale through your nose and try to feel how your abdomen fills up with air like a balloon; exhale*

through your mouth with pursed lips. Just concentrate on your abdomen moving out and in and your back expanding as you breathe, and try to relax and feel comfortable."

b. Let the client rest for two minutes.

c. Repeat this training for additional five minutes.

9. Homework:

a. The client should use resonance frequency breathing technique with abdominal pursed lips breathing with a home breathing trainer (where available), 20 minutes two times a day.

b. Instruct the client to begin by monitoring respiration rate with a watch or a downloaded computer breath pacer for one to two minutes and then to shift to using the home breathing trainer (where available). Breathe at the rate that maximizes smoothness of the curve and amplitude of heart rate oscillations.

c. Remind the client to breathe out longer than in.

d. Remind the client to practice abdominal pursed lips breathing.

e. Instruct the client: "*Breathe easily and comfortably. Do not try too hard.*"

f. Instruct the client to be aware of hyperventilation symptoms and to breathe more shallowly if they occur.

g. Heart rate should go smoothly up and down with the maximum possible amplitude while breathing at resonance frequency.

h. Instruct the client about use of the technique: "*We think that practicing biofeedback two times a day will stabilize your autonomic nervous system, lungs, blood pressure, and emotion. We think it will prevent your symptoms from arising or lessen their severity. Please do your best to practice the technique regularly. We don't know if it will have any immediate effects on symptoms, so regular practice and mastery of the technique are very important.*" Mention that regular practice is important for good results over the long term.

Visits 4–5

1. Connect the sensors to the client.

2. Review the breathing technique. Review pursed lips abdominal resonance frequency breathing with longer exhalation than inhalation. Monitor hyperventilation symptoms:

a. "*First let's review slow breathing. Breathe easily and comfortably rather than deeply. Do not try too hard. If you experience hyperventilation symptoms, I will ask you to breathe more shallowly. I will help you monitor it throughout the visit. Please try to breathe using your diaphragm as you were doing before. Inhale through your nose and try to feel how your abdomen fills up with air like a balloon, exhale through your mouth with pursed lips.*"

3. Biofeedback: practice resonance frequency breathing.

a. Have the client perform paced breathing for about five minutes at resonance frequency, following the breathing pacer.

b. Instruct the client to maximize HRV using a cardiotachometer as biofeedback. Instruct the client to do this by breathing in phase with heart rate changes. Remind the client not to breathe too deeply, particularly if experiencing dizziness or lightheadedness.

c. "*Look at this red line (point to the cardiotachometer tracing). When your heart rate goes up, this red line goes up. When it goes down, the line goes down. Breathe in phase with your heart rate. When your heart rate goes up, breathe in. When your heart rate goes down, breathe out.*"

4. HRV biofeedback (two to five minutes). Use the pacer only where needed. Have the client perform HRV-paced abdominal pursed lips breathing for five minutes at the resonance frequency. Let the client look at the pacer where necessary.

a. "*Continue to breathe in phase with your heart rate. When your heart rate goes up, inhale. When it goes down, exhale. Make your heart rate go up as far as possible and down as far as possible. Continue breathing out longer than you breathe in. Breathe so that the changes in heart rate with each breath are the biggest.*"

b. "*Breathe easily and comfortably rather than deeply. Please try to breathe using your diaphragm as we were doing before. Breathe into your back. Inhale through your nose and try to feel how your abdomen fills up with air like a balloon. Exhale through your mouth with pursed lips. Relax and feel comfortable.*"

c. "*Breathe easily, without tension. Breathe naturally. Don't try too hard. It should just flow almost automatically. Don't think too much about how to do it.*"

d. The therapist notes the client's respiration rate and amplitude of HRV and the LF spectral peak. If the peak diminishes, instruct the client to change the respiration rate up or down to the approximate resonance frequency. The LF peak may be higher than at the previously measured resonance frequen-

cy; if so, instruct the client that this is the new resonance frequency for home practice.
5. Let the client rest for two minutes.
6. Repeat this training for additional five minutes.
7. Discuss the application of biofeedback technique to manage symptoms in daily life. Here, the instructions will depend on the client's individual problems and personality. All of the complex and subtle issues involved in sensitive conduct of psychotherapy are relevant here. They will not be discussed in the current paper.

Instructions prior to end of treatment

"*In order to support improvement in your condition, you should continue practicing the breathing exercises you have learned. These will train reflexes that will help you to control your stress reactions, your autonomic nervous system, and many of your symptoms. Practice twice each day, 20 minutes each time for about two more months. Afterward, practice every few days, just to keep the reflex exercised and functional.*"

"*Definitely use resonance breathing techniques whenever you have an exacerbation of your symptoms or you feel that your symptoms may get worse.*"

"*The resonance breathing technique will help you not only to lessen the severity of your symptoms or avoid them, but also to cope with stressful situations in everyday life, to sleep better, and to improve performance on cognitive and physical tasks. It has no side effects, and you should find it pleasant and helpful.*"

Acknowledgement

Development and refinement of this protocol was supported by Grant # R01HL09295 to Paul Lehrer from the National Institutes of Health.

References

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

Hallman, D. M., Olsson, E. M., von Scheele, B., Melin, L., & Lyskov, E. (2011). Effects of heart rate variability biofeedback in subjects with stress-related chronic neck pain: A pilot study. *Applied Psychophysiology & Biofeedback*, *36*, 71–80. doi:10.1007/s10484-011-9147-0

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

Henriques, G., Keffer, S., Abrahamson, C., & Horst, S. J. (2011). Exploring the effectiveness of a computer-based heart rate variability biofeedback program in reducing anxiety in college students. *Applied Psychophysiology & Biofeedback*, *36*, 101–112. doi:10.1007/s10484-011-9151-4

Karavidas, M. K., Lehrer, P. M., Vaschillo, E., Vaschillo, B., Marin, H., Buyske, S., Radvanski, D., et al. (2007). Preliminary results of an open label study of heart rate variability biofeedback for the treatment of major depression. *Applied Psychophysiology & Biofeedback*, *32*, 19–30.

Katsamanis, M., Lehrer, P. M., Escobar, J. I., Gara, M. A., Kotay, A., & Liu, R. (2011). Psychophysiologic treatment for patients with medically unexplained symptoms: A randomized controlled trial. *Psychosomatics*, *52*, 218–229. doi:10.1016/j.psym.2011.01.015

Lehrer, P. M. (2007). Biofeedback training to increase heart rate variability. In P. Lehrer, W. Sime, & R. L. Woolfolk (Eds.), *Principles and practice of stress management* (3rd ed., pp. 227–248). New York: Guilford Press.

Lehrer, P. M. (2013). How does heart rate variability biofeedback work? Resonance, the baroreflex, and other mechanisms. *Biofeedback*, *41*, 26–31.

Lehrer, P., Karavidas, M. K., Lu, S.-E., Coyle, S. M., Oikawa, L. O., Macor, M., Calvano, S.E., et al. (2010). Voluntarily produced increases in heart rate variability modulate autonomic effects of endotoxin induced systemic inflammation: An exploratory study. *Applied Psychophysiology & Biofeedback*, *35*, 303–315.

Lehrer, P. M., Vaschillo, E., & Vaschillo, B. (2000). Resonant frequency biofeedback training to increase cardiac variability: Rationale and manual for training. *Applied Psychophysiology & Biofeedback*, *25*, 177–191.

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

Lehrer, P. M., Vaschillo, E., Vaschillo, B., Lu, S.-E., Scardella, A., Siddique, M., & Habib, R. H. (2004). Biofeedback treatment for asthma. *Chest*, *126*, 352–361.

Lin, G., Xiang, Q., Fu, X., Wang, S., Wang, S., Chen, S., Shao, L., et al. (2012). Heart rate variability biofeedback decreases blood pressure in prehypertensive subjects by improving autonomic function and baroreflex. *Journal of Alternative & Complementary Medicine*, *18*, 143–152.

Meule, A., Freund, R., Skirde, A. K., Vogele, C., & Kubler, A. (2012). Heart rate variability biofeedback reduces food cravings in high food cravers. *Applied Psychophysiology & Biofeedback*, *37*, 241–251. doi:10.1007/s10484-012-9197-y

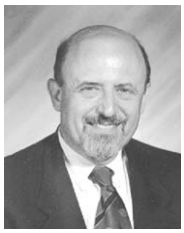
Reineke, A. (2008). The effects of heart rate variability biofeedback in reducing blood pressure for the treatment of essential hypertension. *Dissertation Abstracts International: Section B: The Sciences and Engineering*, *68*(7-B), 4880.

Siepmann, M., Aykac, V., Unterdorfer, J., Petrowski, K., & Mueck-Weymann, M. (2008). A pilot study on the effects of heart rate variability biofeedback in patients with depression and in healthy subjects. *Applied Psychophysiology & Biofeedback*, *33*, 195–201. doi: 10.1007/s10484-008-9064-z

Vaschillo, E., Vaschillo, B., & Lehrer, P. (2004). Heartbeat synchronizes with respiratory rhythm only under specific circumstances. *Chest, 126*, 1385–1387.

Vaschillo, E. G., Vaschillo, B., & Lehrer, P. M. (2006). Characteristics of resonance in heart rate variability stimulated by biofeedback. *Applied Psychophysiology & Biofeedback, 31*, 129–142.

Yasuma, F., & Hayano, J. (2004). Respiratory sinus arrhythmia: Why does the heartbeat synchronize with respiratory rhythm? *Chest, 125*, 683–690.



Paul Lehrer

Bronya Vaschillo

Terri Zucker

Jessica Graves

Maria Katsamanis

Milisyaris Aviles

Frederick Wamboldt

Correspondence: Paul Lehrer, PhD, Rutgers–Robert Wood Johnson Medical School, Department of Psychiatry, 671 Hoes Lane, Piscataway, NJ 08854, email: lehrer@umdnj.edu.