9

Heart Rate Variability

I begin this chapter with a brief overview of relevant cardiac physiology. This section is intended for those who would like a refresher in cardiac physiology. If you are already well versed in physiology, this section may be something you glance through. Next, I introduce the concept of heart rate variability (HRV). In explaining the importance of HRV, I include a brief overview of supporting research. At the end of the chapter, I describe the main components of HRV and introduce a complete HRV training protocol that you can implement with your clients.

Relevant Physiology

The heart is a muscular organ that is responsible for pumping blood throughout the body with rhythmic contractions. The human heart has four chambers: two atria and two ventricles. The atria receive blood and the ventricles pump it out. Deoxygenated blood enters the right atrium, then goes into the right ventricle, and is then pumped out through the pulmonary arteries into the lungs. Reoxygenated blood returns from the lungs to the left atrium, then enters the left ventricle, and is then pumped out through the aorta to the rest of the body.

Cardiac contractions are controlled by natural pacemakers: the sinoatrial node (SA) and the atrioventricular (AV) node. These nodes are self-excitable, meaning that they contract without any signal from the nervous system (they will continue contracting even if they are removed from the body). The SA node generates electrical impulses (action potentials; see Chapter 10 on surface electromyography (sEMG)

The Clinical Handbook of Biofeedback: A Step-by-Step Guide for Training and Practice with Mindfulness, First Edition. Inna Z. Khazan.

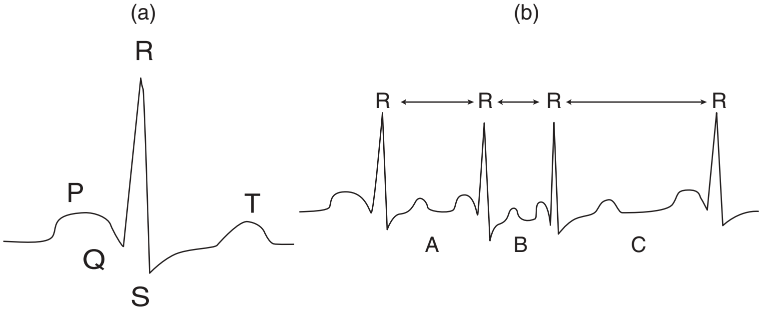

Figure 9.1 (a) The normal ECG complex PQRST; (b) An ECG with three R-R intervals. Reprinted from Azuaje *et al.* (1999) with permission from Elsevier.

for a description), much like the nerve cells do. In a healthy heart, the action potential originates in the SA node, then spreads through the atria, causing both atria to contract in unison. The impulse then passes through the AV node, where the signal is delayed for 0.1 second in order to give the atria a chance to empty completely before the impulse reaches the ventricles, causing them to contract. This cycle of events, from the beginning of one heartbeat to the beginning of the next heartbeat, is called the *cardiac cycle*.

The electrocardiogram (ECG) detects and records these electrical impulses as they are conducted through bodily fluids to the skin. An ECG recording reflects this electrical activity as a series of waves. A typical ECG recording of the cardiac cycle (heartbeat) consists of a P wave, a QRS complex, a T wave, and a U wave (see Figure 9.1a). Each of the waves and intervals between them is associated with different areas of heart function and can be used to assess the health of the heart. Most of the specifics of the ECG recordings are beyond the scope of this book. What you need to know is the significance of the R wave. The R wave represents the contraction of the ventricles (heartbeat). The R-R interval, also referred to as the beat-to-beat interval or the normal-to-normal (NN) interval, represents the time interval between heartbeats. Please see Figure 9.1b for illustration.

Heart Rate Variability

Heart rate variability is the variation in the time interval between heartbeats. As most other systems in the body, our heart rate is never constant. Our heart rate is always changing; meaning that the time interval between heartbeats is either increasing or decreasing. If you look at an ECG recording in Figure 9.1b, notice that the first R-R time interval A is different from R-R interval B, which, in turn, is different from R-R interval C.

This may seem counterintuitive to some of you – we generally think about a low steady pulse or heart rate as healthy. Therefore, how can an ever-changing heart rate be a good thing? In order to answer this question, let me first discuss the difference between the pulse or heart rate and HRV. I then go on to talk about the importance of HRV.

Pulse and heart rate are essentially the same thing, with a few rare exceptions, which are beyond the scope of this book. They reflect the rhythmic contractions of the ventricles of the heart (the lower chambers of the heart). If you've ever taken a pulse, you count the number of heart beats (ventricle contractions) per unit of time (usually a minute). This is the number that we expect to remain steady and, at rest, low. Heart rate variability is not something you can feel or identify without instrumentation. Again, HRV is the subtle variation of the time interval between heartbeats.

An ECG shows the electrical signal generated by the heart. When doing biofeedback, you are not likely to be looking at raw ECG data. Instead, biofeedback software translates the ECG signal into a heart rate wave graph, where each point represents instantaneous heart rate. More specifically, when the software detects an R peak, it calculates the time since the previous R peak, and then determines the number of heartbeats per minute that would have occurred if your heart rate did not change within that minute, and all R-R intervals were the same. This is called instantaneous heart rate, which, when plotted on your screen over time, constitutes a sinusoid-like wave as a sequence of corresponding points on the graph. In simple terms, HRV reflects the rhythmic accelerations and decelerations of the heart rate, which are evident by the rise and fall of this sinusoidal wave. Heart rate accelerates (increases) when R-R intervals shorten and heart rate decelerates (decreases) when R-R intervals lengthen. The accelerations and decelerations of the heart rate wave are also referred to as heart rate oscillations. See Figure 9.2 for illustration.

Now, let us talk about the purpose of HRV or oscillations. The amplitude and complexity of these oscillations are an indication of the body's ability to self-regulate. That is, the greater the amplitude and complexity of heart rate oscillations, the better off the person is.

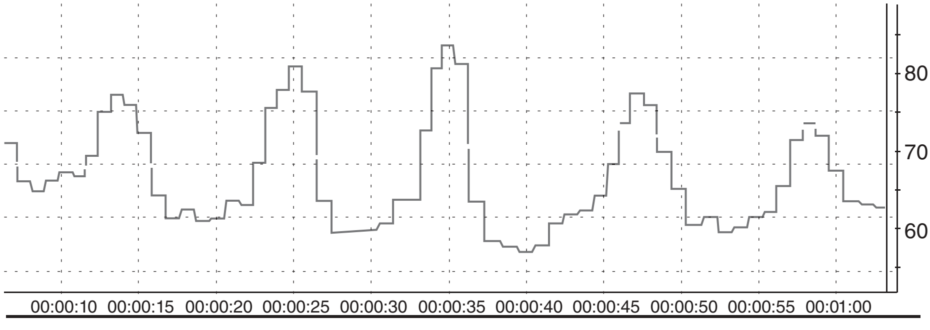

Figure 9.2 Heart rate variability oscillations. Screen shot taken with Thought Technology BioGraph Infinity software (Montreal West, Quebec, Canada).

Paul Lehrer (2007) describes it as a necessary component of the negative feedback mechanism that regulates heart rate and blood pressure. That is, as blood pressure increases, baroreceptors (stretch receptors located in the blood vessels) detect the rise in blood pressure and send a signal for the heart rate to slow down, which brings down the blood pressure. As blood pressure decreases, the baroreceptors send a signal to increase the heart rate and therefore raise the blood pressure. Both the heart rate and blood pressure continuously oscillate in maintaining homeostasis, that is, bringing the body physiology back to equilibrium after it has been disrupted.

When this system is functioning properly, the body is able to self-regulate and restore equilibrium each time it gets disrupted. However, when HRV decreases, the body's ability to self-regulate becomes compromised. There exists a significant body of research demonstrating the importance of HRV for physical and emotional well-being. Specifically, decreased HRV is associated with greater mortality in patients who have suffered a myocardial infarction (e.g., Bigger *et al.*, 1993; La Rovere *et al.*, 1998), with the existence of chronic coronary heart disease (Bigger *et al.*, 1995), and with greater risk for life-threatening arrhythmias (La Rovere *et al.*, 2001). Decreased HRV is also associated with higher risk of hypertension (e.g., Schroeder *et al.*, 2003), diabetic neuropathy (Skinner *et al.*, 2011); fibromyalgia (e.g., Cohen *et al.*, 2000; Martínez-Lavín *et al.*, 1998), anxiety (e.g., Friedman, 2007; Shinba *et al.*, 2008; Licht *et al.*, 2009), panic disorder (e.g., Klein *et al.*, 1995; McCraty *et al.*, 2001; Petrowski *et al.*, 2010; Diveky *et al.*, 2012), posttraumatic stress disorder (PTSD; e.g., Hauschildt *et al.*, 2011; Tan *et al.*, 2011), and depression (e.g., Musselman *et al.*, 1998; Kemp *et al.*, 2010; Taylor, 2010).

Moreover, a significant body of research has also demonstrated that increasing HRV is related to improvements in symptoms of asthma (Lehrer *et al.*, 1997, 2004), coronary artery disease (Cowan *et al.*, 2001; Del Pozo *et al.*, 2004; Nolan *et al.*, 2005), chronic obstructive pulmonary disease (COPD; Giardino *et al.*, 2004), fibromyalgia (e.g., Hassett *et al.*, 2007), heart failure (Swanson *et al.*, 2009), hypertension (e.g., McCraty *et al.*, 2003; Joseph *et al.*, 2005; Nolan *et al.*, 2010, 2012), irritable bowel syndrome (e.g., Humphreys and Gevirtz, 2000; Sowder *et al.*, 2010), major depressive disorder (e.g., Karavidas *et al.*, 2007; Siepmann *et al.*, 2008), performance anxiety (Thurber *et al.*, 2010), and PTSD (Zucker *et al.*, 2009; Tan *et al.*, 2011). There is also some early evidence that increased HRV is associated with improvement in migraine headaches.

Sources of HRV

Heart rate variability oscillations are a reflection of the interaction between sympathetic and parasympathetic branches of the autonomic nervous system. Sympathetic nervous system increases the heart rate, while parasympathetic nervous system puts on the brakes and brings the heart rate down. This phenomenon is called respiratory sinus arrhythmia, or RSA, which refers to the rhythmic fluctua-

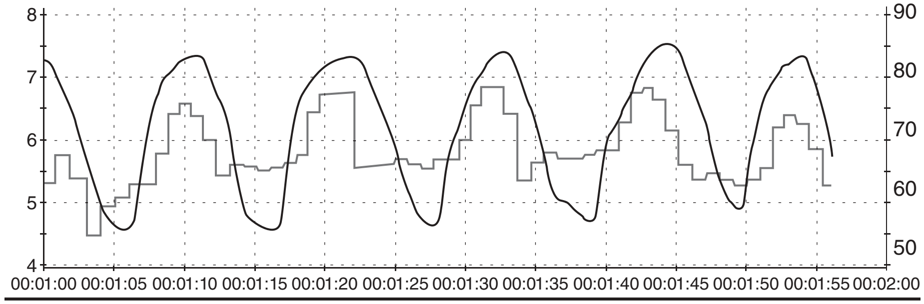

Figure 9.3 Respiratory sinus arrhythmia (RSA). Screen shot taken with Thought Technology BioGraph Infinity software.

tion of the heart rate that accompanies breathing – with the heart rate increasing with each inhalation and decreasing with each exhalation (see Figure 9.3). This synchronous fluctuation happens because the sympathetic nervous system is activated with each inhalation and the parasympathetic nervous system is activated with each exhalation. RSA is the first source of HRV.

Steven Porges (1995, summarized by Gevirtz, 2007) has theorized that the main component of the RSA is the activity of the vagus nerve. The vagus nerve is the tenth of twelve paired cranial nerves. Its parasympathetic fibers branch out to innervate most organs, including the heart, lungs, and stomach. Porges formulated the polyvagal theory, which conceptualizes the role of the vagus nerve from the evolutionary perspective. According to this theory, the human autonomic nervous system has evolved with three distinct circuits: immobilization, mobilization, and social communication/engagement. Porges suggested that withdrawal or stimulation of vagal input to the heart can activate or quiet a person. That is, vagal withdrawal allows autonomic arousal and vagal stimulation shuts it down.

Porges hypothesized that RSA is a reflection of parasympathetic or vagal tone. Activity of the vagal fibers is the brake that slows down the heart during an exhalation in RSA, while the inhibition of vagal activity allows the increase in the heart rate during an inhalation. Strong vagal tone is important for proper autonomic functioning, including RSA and, therefore, sufficient HRV. Specifically, strong vagal tone is necessary for producing maximum increase of the heart rate during inhalation and maximum decrease of the heart rate during exhalation.

An additional benefit of RSA is increased respiratory efficiency. As shown by Yasuma and Hayano (2004) and described by Giardino *et al.* (2003), RSA promotes respiratory efficiency by increasing blood flow during inhalation, when oxygen concentration in the alveoli is at its highest.

The second source of HRV is the baroreflex. Paul Lehrer (2007) provided a comprehensive description of the baroreflex contribution to HRV. Baroreflex refers to the body's ability to regulate blood pressure. Baroreceptors are stretch receptors located in the aorta and carotid artery which respond to changes in the diameter of these blood vessels, and therefore to changes in blood pressure. As described earlier, in response to increased blood pressure, baroreceptors send a signal to the brain to decrease heart rate and vascular resistance (increasing diameter of blood vessels), which subsequently result in a decrease in blood pressure. When baroreceptors pick up a dilation of the blood vessels and a decrease in blood pressure, they send a signal to the brain to increase heart rate and vascular tone. And then the cycle continues in this fashion. Therefore, the baroreflex is a negative feedback mechanism that helps maintain homeostasis.

The strength of the baroreflex is measured in units of change in the beat-to-beat interval on the ECG (measured in milliseconds) per unit of change in blood pressure (measured in mmHg, millimeters of mercury). Given that HRV is the variation in the time between heartbeats, the connection between baroreflex and HRV becomes clear – a stronger baroreflex contributes to greater HRV and vice versa.

Resonance Frequency

Resonance frequency (RF) training is one of the primary mechanisms for increasing HRV. In this section, I describe what RF is and how it applies to HRV. I use this information later in describing HRV biofeedback training. Before proceeding with RF discussion, let us define relevant concepts that I refer to throughout this section: frequency, period, amplitude, and power.

Frequency is the number of cycles per time unit in a wave. Some waves are oscillating faster (higher frequency, many cycles per second), some are slower (lower frequency, fewer cycles per second; see Figure 9.4). Frequency is measured in Hertz (Hz).

Period is the duration of each cycle. Period and frequency are inversely related. The longer the period, the fewer cycles occur in each second. Hence, the frequency of the signal is lower. Conversely, the shorter the period, the more cycles occur in each second, and the frequency of the signal is higher. For example, in Figure 9.4, the faster frequency wave on the left has a shorter period than the slower frequency wave on the right.

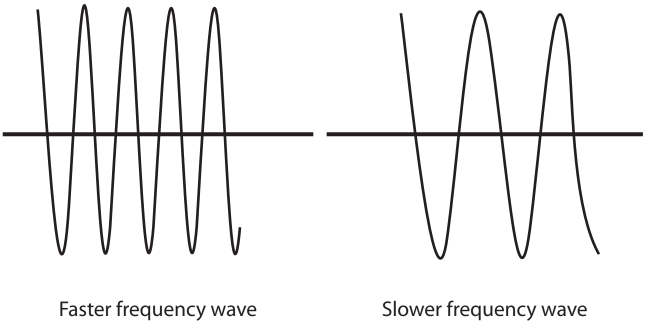

Figure 9.4 Faster (left) and slower (right) frequency wave.

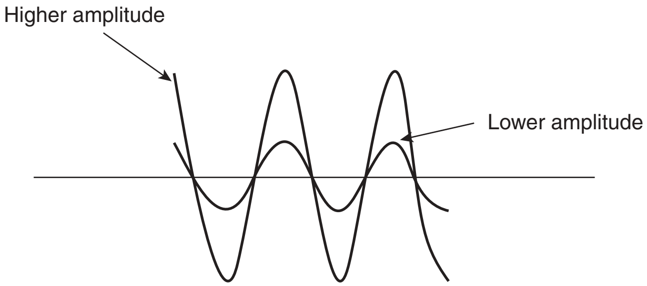

Figure 9.5 Higher and lower amplitude oscillations.

Amplitude is the difference between the highest and lowest point on each cycle. See Figure 9.5 for illustration.

Power reflects the amplitude of the signal relative to its frequency. It is actually measured as the square of amplitude divided by frequency. If we have two waves of the same frequency, the one with higher amplitude carries more power. Similarly, given equal amplitudes, the signal with lower frequency carries more power than the signal with higher frequency. This makes sense if you think about the periods. The wave with the longer period (i.e., lower frequency) lasts longer and carries more power.

Now, let us continue talking about resonance. Resonance is the predisposition of certain systems to oscillate with greater amplitude at some frequencies of stimulation than others. For example, if you stimulate a pendulum with one tap every 7 seconds, the amplitude of its oscillations will be different than if you stimulate the same pendulum with one tap every 5 seconds. One frequency of stimulation, as well as its multiples or harmonics, will produce maximum oscillations of the pendulum. It might help to think about a swing – you can usually find a frequency of pushing it that produces maximum regular swings. That frequency of pushing is the swing's RF.

Remember that the goal of HRV biofeedback is to maximize the amplitude of oscillations. Therefore, it is possible to determine one specific frequency that will stimulate the heart rate to produce maximum oscillations. Breathing is the most reliable and easily accessible way of stimulating the heart rate. Breathing at a particular frequency provides the stimulation necessary to maximize HRV. This frequency is called *resonance frequency breathing rate*.

Because I am talking about breathing as a way of stimulating the heart rate, I am going to refer to a single possible RF breathing rate. In theory, there are numerous frequencies, all multiples (harmonics) of each other, that can serve as RFs. However, because in practice the human breathing rate is not unlimited, I will refer to RF breathing as a single possible breathing rate.

While the exact RF of breathing is different for different people, Eugene Vaschillo, Paul Lehrer and their colleagues have determined that for most people the RF lies somewhere between 4.5 and 7 breaths per minute (bpm; e.g., Vaschillo *et al.*, 1983, 2002; Lehrer *et al.*, 2000). In the succeeding paragraphs, I describe the HRV training protocol, based on the protocol described by Paul Lehrer (Lehrer *et al.*, 2000; Lehrer, 2007) which includes determination of RF of breathing for a client.

Systems with resonance characteristics will continue oscillating after the initial stimulation is no longer present. If you stimulate a pendulum once, it will continue oscillating, with steadily decreasing amplitude, for a while. For some systems these oscillations are more complex than others. As an example, give your table or desktop a firm tap right now – you hear the thump, and not much else. Now try something else: if you have an empty glass nearby, hit it gently with a pen or a spoon. Can you hear the sound continuing to reverberate after the initial ding? Oscillations of the glass produce sound which is much more complex than the oscillations which produce the tabletop sound. Increasing the complexity of the heart rate frequencies is another goal of HRV biofeedback (for more details, please see Giardino *et al.*, 2000). RF breathing training helps to achieve this goal together with increasing the amplitude of heart rate oscillations.

Selected Methods of Measurement of HRV

There are numerous ways of measuring HRV. I am going to review only those few that are most applicable to your work and the ones you are most likely to encounter. If you are interested in reading more, please see the 1996 guidelines published by the Task Force of The European Society of Cardiology and The North American Society for Pacing and Electrophysiology. The article is titled: "Heart rate variability: Standards of measurement, physiological interpretation and clinical use."

There are two types of methods of measuring HRV: time-domain methods and frequency-domain methods. Time-domain methods determine the variability of NN intervals. NN interval is the R-R interval, or the time between heartbeats (also referred to as instantaneous heart rate). In the following list, I review several of the most often used time-domain methods.

- *SDNN* is the standard deviation (square root of variance) of NN intervals over a certain period of time. It is the simplest to perform and most common method of measuring HRV in research. It is often performed over a 24-hour period. However, clinical use of SDNN measurement is tricky because of the dependence of this method on the time interval of the recording. The total variance of HRV increases with the time of recording. Therefore, one cannot accurately compare SDNN of two time periods of different lengths, and longer (24 hours) recording is preferable. In clinical practice, we rarely have an opportunity for such long recording, and don't always compare equal time periods of recording. It is possible to use SDNN clinically, with careful attention to comparing similar time periods and keeping in mind that short recordings may be less accurate. The greater the variance of NN intervals, the higher the HRV.

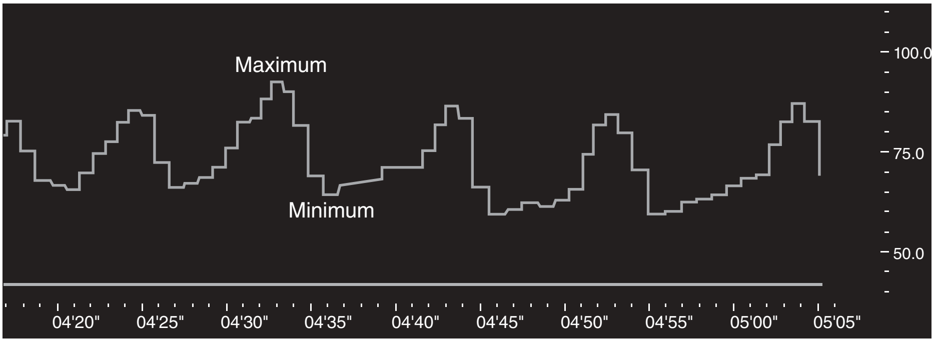

Figure 9.6 Maximum–minimum HRV. Screen shot taken with NeXus BioTrace$^+$ software (Mind Media, Roermond-Herten, The Netherlands).

- *rMSSD* is the square root of the mean of the squares of the differences between adjacent NN intervals. This measure is used primarily in research.
- *NN50* is the total number of pairs of consecutive NN intervals that differ by more than 50 milliseconds. A related measure, pNN50, is a proportion derived by dividing NN50 by the total number of NN intervals. These measures are also used primarily in research.
- *Peak-to-trough* (or maximum–minimum) is the measure of HRV that you are most likely to use clinically. In technical terms, it is the difference between the shortest R-R interval occurring during inspiration and the longest R-R interval occurring during expiration. In simpler terms, it is the difference between the maximum and minimum (max–min) heart rate that occurs during a full breath cycle (see Figure 9.6). This is measured over many breath cycles. Results may be presented either as an average max–min difference over several minutes or as a graph of individual max–min differences for each breath cycle. The bigger the max-to-min difference, the higher the HRV. Note that the HRV recording has to be 5 minutes or longer in order for this measure to be accurate.

Frequency-domain measures focus on analyzing the rhythmic fluctuations that make up the overall variability of the heart rate.

Power spectral analysis is a frequency-domain measure that uses an algorithm called the fast Fourier transform (FFT) to decompose the heart rate wave into its individual frequency components. To understand this better, think about looking at white light through a prism. Similar to FFT, the prism separates all the frequencies in the light wave, enabling you to see a rainbow. Biofeedback equipment works much like a prism to translate the heart rate into an illustration of different frequencies that the heart rate is composed of. These frequencies are displayed on the frequency domain graph. On this graph, three separate ranges of frequencies are typically identified, for example, by using different colors (see Figure 9.7).

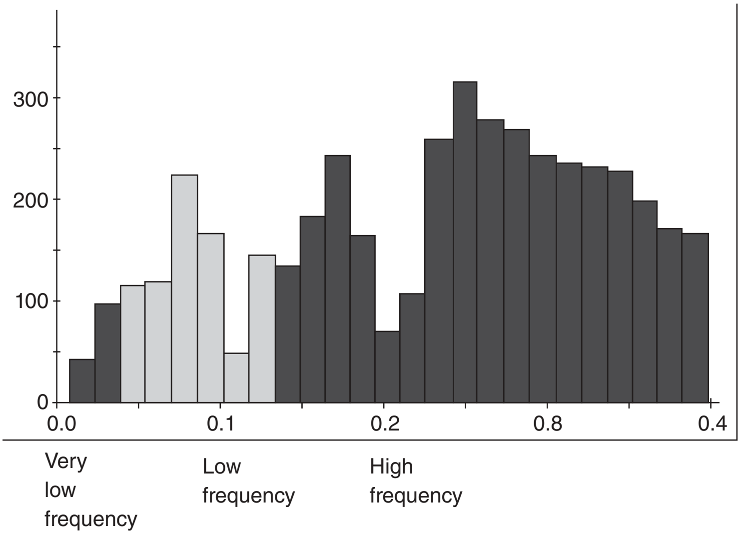

Figure 9.7 Spectral analysis of HRV. Screen shot taken with Thought Technology BioGraph Infinity software.

Power spectral analysis displays the relative power of each component frequency of the heart signal at each moment in time. The three ranges of frequencies that are identified by the biofeedback equipment are: high frequency (HF), low frequency (LF) and very low frequency (VLF).

High frequency signal is in the range of 0.15–0.4 Hz. This component of the heart rate signal reflects parasympathetic and respiratory influences on the heart. This component is also a reflection of the vagal tone.

Low frequency signal is in the range of 0.05–0.15 Hz. This component of the heart rate signal reflects the baroreflex function (blood pressure maintenance).

RF breathing happens in practice only within this range of frequencies, typically around 0.1 Hz, which is equivalent to 6 bpm (0.1 Hz = 0.1 cycle/s = 1 cycle/10 s = 6 cycles/min). RF breathing produces a peak of power at LF. This peak has been termed the “meditator’s peak,” because it is associated with the most calm physiological state, such as one achieved by experienced meditators. This is the peak that will help you determine the RF breathing rate discussed in the next section. See Figure 9.8 for illustration.

Very low frequency signal is in the range of 0.005–0.05 Hz. This component of the heart rate is primarily influenced by the sympathetic nervous system.

LF/HF is a ratio that you will encounter in the literature, and that some types of biofeedback software allow you to calculate. This ratio reflects the relative amounts of LF and HF power and is generally understood as a measure of the balance between sympathetic and parasympathetic nervous system activity.

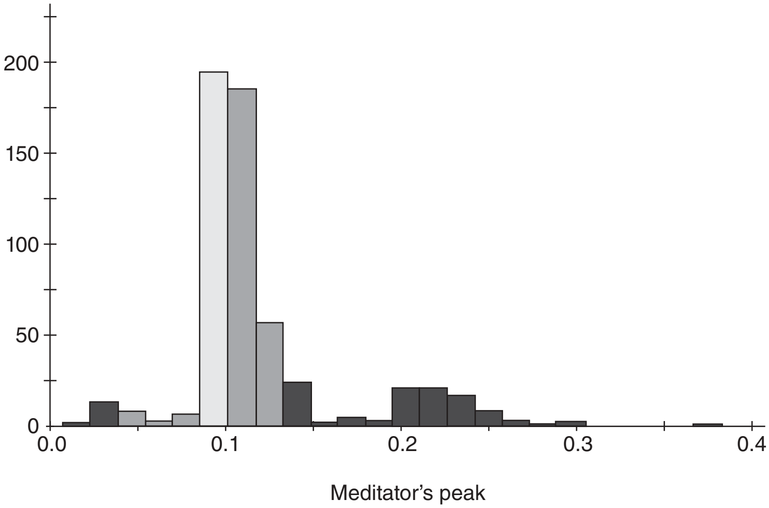

Figure 9.8 Low frequency "meditator's" peak. Screen shot taken with Thought Technology BioGraph Infinity Software.

Determining Resonance Frequency (RF) Breathing Rate

Vaschillo, Lehrer, and colleagues found that for most people, the RF breathing rate is between 4.5 and 7 bpm. The average RF breathing rate is 6 bpm. If your equipment allows, it is best to determine the RF breathing rate as precisely as possible in order to help your clients gain maximum benefit from HRV biofeedback. Remember that there is only one practically possible frequency of breathing that will stimulate the heart rate to produce maximum oscillations or variability. Individual differences in RF breathing are related to variables like height and gender, since it is affected by differences in the relative size of the circulatory system and the overall blood volume (Vaschillo *et al.*, 2006).

Before proceeding with RF breathing rate determination, I suggest first doing some basic breathing training to make sure that your clients are not overbreathing while practicing RF breathing. Please refer to Chapter 8 on breathing for instructions. Once the client is comfortable with "low and slow" diaphragmatic breathing with pursed lips exhalation, begin breathing training using a pacer.

Many biofeedback software programs have an integrated pacer that you can set to a certain number of breaths per minute and adjust the proportion of inhalation to exhalation time. If your software does not have a built-in pacer, there is one available from the Biofeedback Foundation of Europe website (www.BFE.org). It is also possible to get free or inexpensive breathing pacing applications for smartphones (i.e., iPhone and Android-based phones).

Allow the client to practice using the pacer at a rate similar to her baseline breathing rate and a 40 : 60 proportion of inhalation to exhalation. Then gradually bring the pace of breathing down until the client is able to breathe at 7 bpm. Some people will be able to breathe at that pace almost right away, while others may need one or two steps down, while those who are used to very fast breathing may need a longer step-down process.

For example, if a client's baseline breathing rate is 15 bpm, set the pacer at 12 bpm first and ask the client to breathe at that rate for a minute or two. If she is comfortable breathing at this rate, bring it down to 10 and then to 7 bpm. If 12 bpm is difficult, allow for a more gradual step down, lowering the pace by 2, 1.5, 1, or even 0.5 bpm at each step.

A common problem during paced breathing training is difficulty with a longer exhalation at lower breathing rates – people often say that they run out of breath before the exhalation is over. If your client is having this problem, ask her to slow down the very beginning of the exhalation, since most people breathe out the most air at the very beginning of the exhalation. In addition, ask the client to breathe out through pursed lips giving her more control over air flow than exhalation through the nose.

Once the client is able to breathe comfortably at 7 bpm, move on to the protocol for RF breathing rate determination. This protocol is based on Paul Lehrer's 2007 RSA training protocol. If a capnometer is available, it is helpful to use one to make sure that CO_2 levels do not fall below 35 mmHg by regulating the size and depth of the breaths (see Chapter 8 on breathing for more detailed instructions).

1. Set the pacer at 7 bpm with a 40 : 60 proportion of inhalation to exhalation.
2. Ask the client to breathe diaphragmatically ("low and slow") while following along with the pacer for 3 minutes. See Chapter 8 for complete instructions.
3. Allow 1 minute for your client's physiology to adjust to the new breathing rate, and then begin recording the heart rate, HRV, and the height of the LF peak. Record for 2 minutes. At the same time, observe the RSA (synchronicity between heart rate and breath). Please note that if your biofeedback device measures HRV, but does not have a breathing gauge, you will not be able to assess the RSA. Among devices that record RSA, some allow you to play back the recorded session to assess RSA (e.g., Thought Technology and NeXus 10), while others (e.g., J & J) may not allow playback, so you need to "eyeball" and record your assessment of RSA for each rate of breathing in real time.
4. Set the pacer to 6.5 bpm for 3 minutes (allow 1 minute to adjust to new breathing rate, and record for 2 minutes). Then continue pacing at 6, 5.5, 5, and 4.5 bpm for 3 minutes each (again, with 1 minute to adjust and 2 minutes of recording).
5. Use the following guidelines and the RF template in Table 9.1 to determine the RF breathing rate. Let your client know what her RF breathing rate is.

Table 9.1 Resonance frequency breathing rate determination template.

Breathing rate	*LF peak (record highest peak)*	*Max–min HRV (record highest consistent HRV)*	*Heart rate (by "eyeballing," rate smoothness and regularity of HR on scale 1–5)*	*RSA (by "eyeballing," rate synchronicity of heart rate and breath on scale 1–5)*
7 bpm				
6.5 bpm				
6 bpm				
5.5 bpm				
5 bpm				
4.5 bpm				
Other				

6. You may not need to test every one of the breathing rates, if one clearly stands out as meeting all the following criteria early on. It is helpful to retest this breathing rate and two adjacent ones to make sure your RF determination is correct.

RF breathing is characterized by:

- Highest LF peak (or the period when the LF frequency is highest in percentage relative to other frequencies)
- Highest peak-to-trough (max–min) HRV (be sure to pick highest max–min HRV that is consistently happening throughout the 2-minute recorded interval, and not an aberrant spike that may be due to movement or other artifact)
- Best RSA
- Smooth and regular heart rate.

If one breathing rate produces the highest LF peak and consistently the highest max–min HRV, together with a smooth HR and good RSA, you have the RF breathing rate. Unfortunately, it is often not quite so straightforward and you may need to pick a breathing rate based on its meeting the most characteristics. Typically, the highest LF peak and the highest max–min HRV are the most important characteristics and the ones that are most easily measurable, with no "eyeballing" involved. If one breathing rate produces the best LF peak, but one of the adjacent breathing rates produces the most consistently high max–min HRV, it is safe to conclude that RF is somewhere between those two breathing rates and to train the client to breathe somewhere between those two rates. Most people will not be able to consistently

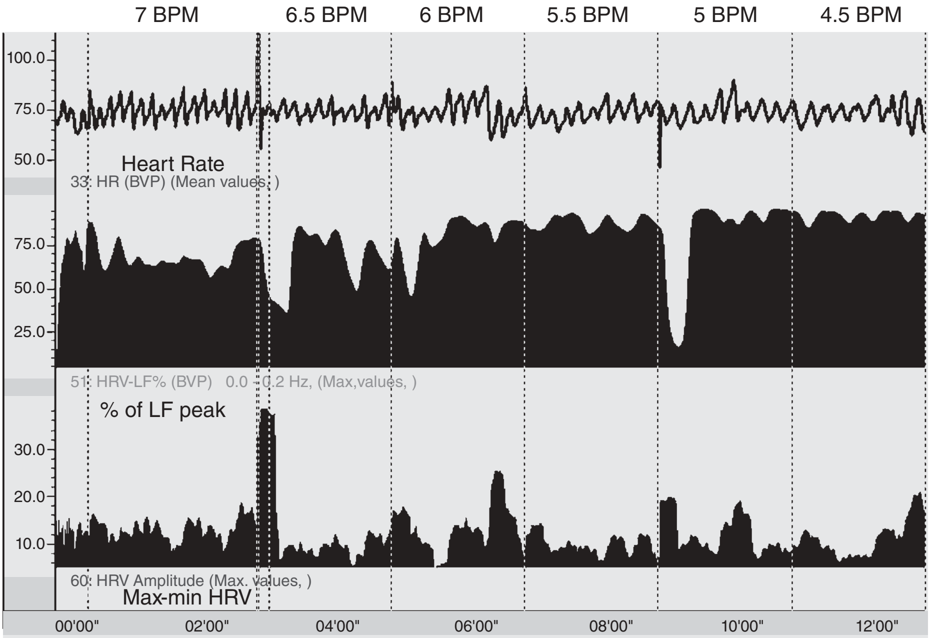

Figure 9.9 Heart rate (top), percent of LF peak, and max–min HRV (bottom) during RF determination. Screen shot taken with NeXus BioTrace$^+$ software.

breathe at a specific rate with 100% accuracy without a pacer, so giving them a small range can be quite helpful. If the highest LF peak and the highest max–min HRV are happening at nonadjacent breathing rates, repeat the measurements for those two breathing rates. If the discrepancy still exists, choose the breathing rate with the highest LF peak. Use Table 9.1 to help you determine RF breathing rate.

Figure 9.9 shows an example of the heart rate, percentage of LF peak, and HRV during RF determination. Based on these data, I determined that RF breathing occurred between 5.5 and 6 bpm. The highest percentage of LF peak occurred at 6 bpm. The highest consistent max–min HRV occurred at 5.5 bpm. Heart rate smoothness and RSA (“eyeballed” during the assessment) were about equal at both 6 and 5.5 bpm.

Training breathing at resonance frequency

Once you have determined the RF breathing rate, it is time to train the client to breathe at that rate.

1. Set the pacer at a client’s RF rate and 40 : 60 proportion of inhalation to exhalation. If you determined the RF to be between two adjacent breathing rates, set the pacer to the slower rate if your client’s tendency is to breathe too fast, and

Table 9.2 Approximate counts for inhalation/exhalation for various breathing rates.

Breathing rate (bpm)	*Total duration of each breath (seconds; rounded to the nearest decimal)*	*Approximate count for inhalation*	*Approximate count for exhalation*
7	8.5	3.5	5
6.5	9.2	3.75	5.5
6	10	4	6
5.5	11	4.5	6.5
5	12	4.75	7.25
4.5	13.3	5.25	8

to the faster rate if your client's tendency is to breathe too slow (such as when learning "low and slow" diaphragmatic breathing).

2. Ask the client to breathe diaphragmatically at RF while following along with the pacer. Ask her to notice how this breathing feels, what is different about it compared with the way she typically breathes.
3. Help the client identify her own internal pacing cues while also following along with the pacer. Different ways of pacing may work for different people. Your clients may come up with their own internal pacers. Some possibilities include:
    - Counting in accordance with the RF rate (refer to Table 9.2 for suggested counts). For example, RF of 6 bpm corresponds to a count of 4 for inhalation and 6 for exhalation, with each count lasting approximately 1 second.
    - Neutral words that form a singsong-like way to adhere to the rhythm of RF breathing. Ask the client to either choose one word for the inhalation and another for exhalation, or choose a two-syllable word or two-word phrase to go along with the whole breath. For example, you could use "blue" for the inhalation and "purple" for the exhalation (slightly longer word for the exhalation). One of my clients used "encyclopedia" for the inhalation and "Britannica" for the exhalation. I suggest staying away from words like "relax" in order not to put pressure to achieve a particular state.
    - Internal sensations that help the client to recognize the ideal breathing rhythm. Your clients will have to develop this on their own. The sensations of the heart rate or a feeling of the blood flowing are likely to be involved. Some people will not be able to develop a cue based on internal sensations, but to others it will be quite easy and obvious. They may or may not be able to describe the sensation to you in words. Mindfulness training is quite helpful in allowing people to identify their internal cues. Encourage your

clients to use practices such as breathing awareness and awareness of body sensations (Appendix I).

4. Once the client is comfortable with her internal pacer, turn the computer screen away from her (or ask her to close her eyes) and ask her to reproduce the RF breathing rate using internal cues for pacing. Let the client practice for 2–3 minutes.
5. Freeze the screen and ask the client how she feels she did with the breathing rate before turning the screen back to her – does the client think the breathing pace was close to RF, too fast, or too slow?
6. Give nonjudgmental mindful feedback and allow the client to see the computer screen. Whatever corrections you might wish for your client to make, make sure to start off with giving positive feedback about what the client is doing well and then make suggestions for improvement.
7. If the client's breathing rate with no feedback is not at RF ±0.5 bpm, give suggestions for adjustment:
   - If the inhalation is too quick or too slow, ask the client to slow down or quicken the inhalation
   - If the exhalation is not long enough (common problem), ask the client to slow down at the very beginning of the exhalation
8. Ask the client to once again breathe at the RF rate, following along with the pacer.
9. Turn the screen away and repeat steps 5–7 again until the client is able to breathe at a rate within 0.5 bpm of the RF with no feedback.
10. Give homework to practice RF breathing at home, preferably once a day for 10–20 minutes each time. A pacer the client can use at home and/or at work is helpful. There are pacers available at www.BFE.org and as an app on most smartphones.
11. At the next session, begin with asking the client to breathe with no feedback (while monitoring the computer screen yourself). Make suggestions for adjustment as necessary (see previous steps). Repeat until the client is breathing within 0.5 bpm of the RF at least 70% of the time.

Sample explanation of HRV and resonance frequency breathing to be provided to the client: (It is helpful to have a pen and paper or dry erase board handy to draw the heart rate sine wave to illustrate or use Figure 9.2 in this chapter as an illustration).

> *Let me first tell you what heart rate variability is. It is the difference in time that passes between each heartbeat. The shorter the time between heartbeats, the faster your heart rate. The longer the time between heartbeats, the slower your heart rate.*

Your heart rate is always changing – sometimes it speeds up, sometimes it slows down. Heart rate variability refers to the difference between maximum and minimum point on the heart rate wave. We have a lot of research evidence showing that the greater someone's heart rate variability is, the better off they are. In fact, greater heart rate variability is associated with better outcomes for people who have heart disease, as well as people who have asthma, high blood pressure, chronic pain, and so on (include issues relevant to your client here). *To put it simply, your heart is a muscle, and we know that the more flexible a muscle is, the healthier it is. Same for your heart – the greater the range of frequencies with which your heart can beat, the more flexible and the healthier it is. The only time when it is OK for a person's heart to beat at the same rate all the time is when they have a pacemaker.*

In addition, your cardiac system is a large part of the autonomic nervous system, which is the system that is responsible for your heart beating, breathing, gastrointestinal function, and so on. When people are under prolonged or chronic stress of any kind, whether it be pain, anxiety, trauma, or general life stress, the autonomic nervous system can get dysregulated and no longer function properly. Increasing your heart rate variability will help strengthen your autonomic reflexes and help restore the functioning of the autonomic nervous system closer to its proper state.

The way we can increase heart rate variability is through breathing. Think about your heart rate as a pendulum, going up and down (it may be helpful to have a pendulum to demonstrate with here). *If we stimulate the pendulum infrequently, it will move only a little. If we stimulate the pendulum very frequently, it will move unevenly. We can find a rate of stimulation of the pendulum that will be just right to produce maximum, even oscillations. Our breathing stimulates our heart rate in a similar way. We can find a rate of breathing that will stimulate the heart rate in a way that produces maximum smooth consistent heart rate oscillations. This breathing rate is called resonance frequency breathing.*

Once we figure out what your resonance frequency breathing rate is, I will teach you how to breathe at that rate and develop some internal cues that will let you know that you are breathing at that rate. You'll be practicing breathing exercises to increase your heart rate variability and help strengthen your autonomic reflexes.

Just to be clear, you won't always need to be breathing at resonance frequency. In fact you should not, since you will need to adjust your breathing rate to your everyday activities. You will only need to breathe at your resonance frequency rate while practicing the skills I teach you. Practicing these skills will function similarly to strength training you might do at the gym: if you exercise for half an hour, three times a week, your strength increases. There is no need to carry dumbbells around with you in order to maintain the gains. Same here – if you practice your breathing skills 20–30 minutes a day, you will exercise and strengthen your autonomic nervous system reflexes and maintain those gains with consistent practice.

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