

## SPECIAL ISSUE

# The Future of Heart Rate Variability Biofeedback

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*The authors describe the oscillations of heart rate and their relationship with blood pressure oscillations. The baroreflex is a key regulator in the cardiovascular system. The baroreflex mechanism determines a resonant frequency, ranging from 9.25–13 seconds, at which maximal oscillations in heart rate will occur. Current research and clinical reports suggest a significant health effect of augmenting this resonant frequency in heart rate variability by means of biofeedback, paced breathing, and other rhythmic stimulation. There is evidence that augmenting heart rate variability—creating maximal oscillations in heart rate at the individual's resonant frequency—may benefit asthma, hyperventilation syndrome, hypertension, hypotension, anxiety, depression, fatigue, and pain.*

### The Physiology of Heart Rate Variability

Work from our laboratory over the past decade or so has focused not only on the phenomenon of heart rate variability (HRV) biofeedback but on its mechanism. Research in Russia, from the 1980s, had found that very high oscillations in heart rate (HR) could be obtained when people breathe slowly, at particular frequencies, at around 6 breaths/minute (or .1 Hz).

There is something interesting about HR oscillations at this frequency. There is a natural rhythm at about this rate that has been observed for many decades and has been given many names by various investigators (10-second wave, the .1 Hz wave, slow waves, low frequency waves, midfrequency waves, Mayer waves, Traub waves, Hering waves, and probably a number of others). There has been much debate about autonomic control of these waves. Although many investigators have thought that they reflect sympathetic activity, or a combination of sympathetic and parasympathetic activity, opinion now seems to be shifting to interpret them as entirely parasympathetic. From our perspective, however, this particular issue has not been resolved because of the very complex nature of autonomic nervous system's (ANS) control of HRV and the complex structure of the ANS (thus rendering it very difficult to interpret the effects of studies using sympathetic or parasympathetic blocking agents to study autonomic mediation of various HRV frequencies.)

### The Baroreflex System

One thing that seems very solid about interpreting the .1 Hz wave, however, is that it is greatly affected by activity of the HR baroreflex. The baroreflex is a fascinating reflex that has profound implications for all of us in the biofeedback field. It is one of the important mechanisms by which blood pressure (BP) lability is controlled and modulated. We have modeled the baroreflex system in engineering terms as a “two closed-loop system.” This means that there are two separate pathways by which the baroreflexes modulate BP.

The pathway that is best studied is the HR loop. This one is responsible for the .1 Hz wave in HR. Each time BP rises, the baroreflex (triggered from stretch receptors in the aorta and carotid artery) causes HR to fall. A lower HR means that there is a smaller volume of blood being projected through the vascular system, thus causing BP to fall. The opposite thing happens when BP falls. The baroreflexes then cause HR to rise, causing a consequent rise in BP. It is in this way that the baroreflex modulates changes in BP. Each time it changes, a consequent change in HR occurs, which reverses the direction of the BP change.

The second loop in this two-loop system involves the vascular tone of the baroreflex. We will return to discuss this second system later.

Regarding the baroreflex HR loop: Although the change in HR is immediate, occurring within a fraction of a second after BP has started to change, the change in BP resulting from changes in HR is delayed by several seconds because of inertia in the blood coursing through the vascular system. As anyone who remembers high school physics will know, the inertia (and therefore, the length of the delay) should be related to the mass of blood in the system. This appears to be so. The BP change is slower in taller people than in shorter people and slower in men than in women (i.e., slower in people with more blood volume). Thus the 10-second wave actually varies among people, from about 9.25–13 seconds.

### Resonant Frequencies and the Cardiovascular System

There is something else that is interesting about this 10-second wave. It reflects resonant characteristics of

the cardiovascular system at this frequency, caused by baroreflex action. Thus, whenever the cardiovascular system is stimulated (by *anything*: physical exercise, emotionally-relevant events or even thoughts, changes in posture or head tilt, breathing, etc.), a set of oscillations takes place that “rings” like a bell, with an array of oscillations that gradually decrease in amplitude over time. The oscillations are caused by the interplay of HR and BP: Stimulus-induced changes cause changes in BP, which cause modulatory changes in HR, which cause delayed changes in BP, which cause more modulatory changes in HR, and so on, in a gradually decreasing function.

Figures 1 and 2 present a model of response of the cardiovascular system to stimuli. Figure 1 shows how the system would look when stimulated if there were no baroreflex at all. An increase in BP would occur, which would eventually subside. Figure 2 shows what happens when the baroreflex system is active. The stimulus causes oscillations in HR and BP, which gradually decrease over time.

What happens, then, when the system is repeatedly stimulated at its resonant frequency, that is, if a stimulus occurs about every 10 seconds? Depending on the timing of the stimulus (i.e., if it comes when HR is rising or falling), its effects will either dampen the amplitude of the HR oscillation or augment it. When a person breathes at the ~.1 Hz resonant frequency, due to phase relationships between HR and BP at this exact frequency, the respiratory stimulus causing HR to rise occurs precisely at the same time as the baroreflex impulse causing HR to rise. The same concurrence happens with the respiratory stimulus causing HR to fall: It occurs precisely when the baroreflex impulse occurs, causing HR to fall. This causes a persistence (and even an increase) of the augmented HR oscillation at the resonant frequency (Figure 3).

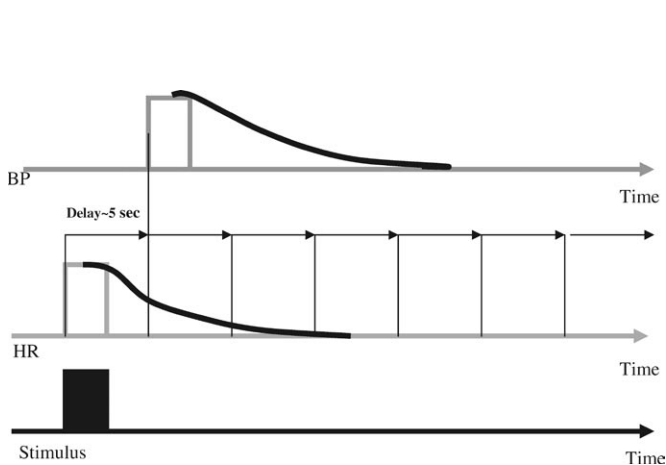


Figure 1. Heart rate and blood pressure reactions to stimuli if the baroreflex does not work.

Why does this happen? The reason is the phase relationships among HR, BP, and respiration when a person breathes at his or her individual resonant frequency. At this frequency (and only at this frequency), we have found that two things happen: HR oscillations and respiration are perfectly in phase with each other (i.e., a 0° phase relationship—HR rises just as the person inhales and falls just as the person exhales), and HR oscillations become very large (i.e., of higher amplitude than will occur at any other respiratory frequency). Additionally, when the system is rhythmically stimulated at this frequency (e.g., by breathing at this frequency), HR and BP oscillate in perfectly *opposite* directions (i.e., an 180° phase relationship, such that BP falls as HR rises and vice versa). This means that the baroreflexes are stimulated with every breath, causing an increase in HR oscillations. Thus, as you inhale, HR rises and BP falls, but the baroreflex causes an immediate augmentation of the respiration-induced HR increase, with the opposite happening as you exhale, causing high-amplitude HR oscillations.

Let us just add a parenthetical bit of confusion here. The 10-second wave is, on average, usually a bit more than 10 seconds. On average, the resonant frequency of healthy adults is actually about 11 seconds.

So what happens when the baroreflex gets stimulated with each breath, causing greater output—greater changes in HR? As in the exercise of any reflex, the reflex becomes more efficient with exercise and works better. It’s like the old New York story about asking directions to Carnegie Hall. To get there, you need to practice. We have found that in healthy people practicing HRV biofeedback daily for about 3 months, the gain in resting baroreflex increases (i.e., a bigger change in HR for each mm Hg change in BP). This means that there now is stronger modulation of BP.

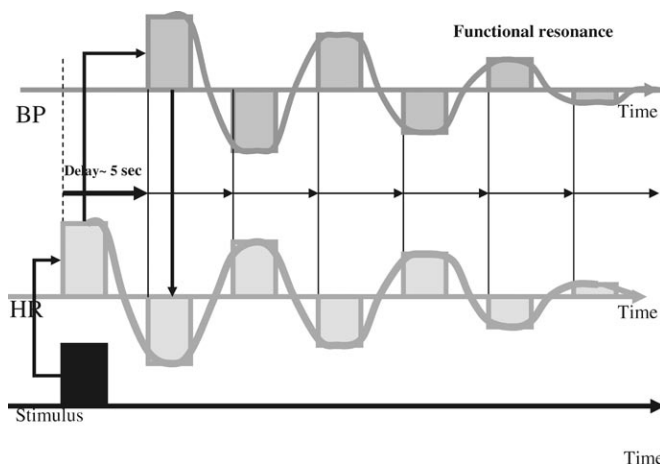
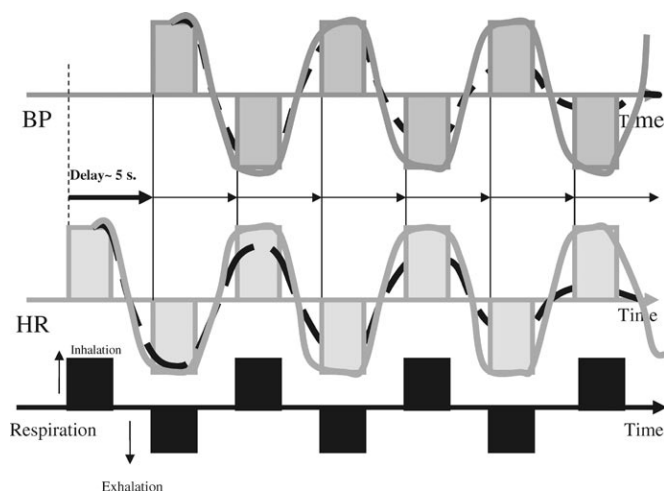


Figure 2. Heart rate and blood pressure reactions to stimuli if the baroreflex works.



**Figure 3.** Heart rate and blood pressure oscillations elicited by the stimulus of respiration.

### Health Effects of Augmenting the Resonant Frequency

Therefore, one would expect that HRV biofeedback would decrease BP lability and all conditions associated with it. Perhaps everything related to neural substrates of BP reactivity also will be modulated, including emotional reactivity. Indeed, animal research has found that stimulation with stress hormones of brain centers involved in baroreflex control (at the nucleus tractus solitarius) causes a decrease in baroreflex gain, with a consequent increase in BP lability. Thus, emotional lability bears a direct relationship to BP lability and baroreflex control. This may explain the wide variety of disorders that seem to respond well to HRV biofeedback or breathing at about .1 Hz: asthma, hyperventilation syndrome, hypertension, hypotension, anxiety, depression, fatigue, pain, etc. These relationships have not all been validated by controlled research, although multiple case reports, as well as a few controlled studies (e.g., on asthma, hypertension, and gastric pain), strongly indicate that this broad range of effects does occur.

Our controlled findings on asthma are remarkably strong, showing a clinically significant decrease in asthma severity, allowing lower doses of anti-inflammatory medication while producing better pulmonary function with fewer symptoms and fewer asthma exacerbations. In 3 months, study participants improved by a full level in the National Institutes of Health's four-step categorization of asthma severity. No changes occurred in control groups. Similarly, a multiple-case study has found effects on major depression to be stronger than those of most selective serotonin reuptake inhibitor drugs. Others have found similarly strong effects on modulating BP and various pain conditions.

### The Future

We expect we will find that a lot of other clinical conditions also respond well to HRV biofeedback. It looks like HRV biofeedback is one of the strongest methods in the biofeedback clinicians' armamentarium. But we also expect to find some other things that promise to be even more exciting.

The first prediction has to do with the nature of resonance. So far we have been discussing respiration as a means of producing HR and BP oscillations at about .1 Hz. However, if the baroreflex system really has characteristics of resonance, then *any* rhythmical stimulation also should cause large oscillations in HR. Indeed, we have recently found that 10-second stimulation with emotionally valent slides, 10-second repetitive tasks, and 10-second muscle tension/relaxation sequences all produce very large increases in HRV at .1 Hz. The oscillations are so large, all other sources of variability seem to disappear. Thus, we would expect that someday we will be producing HRV biofeedback effects by having people do rhythmical exercise, having them listen to music with phrases of about .1 Hz (a method currently employed in the Food and Drug Administration–approved RESPeRATE, a device used for BP control), or doing muscular tension/relaxation sequences about every 10 seconds. Also, we suspect that the oscillations (and therapeutic effects) will be larger when actual resonant frequencies are studied: that is, by stimulating the system at each individual's *exact* resonant frequency.

The second prediction has to do with the second loop in our two-closed-loop model of the cardiovascular system. The second loop is the vascular tone loop of the baroreflex. It is known that as BP rises, baroreflex activity also causes the blood vessels to dilate throughout the body. Thus, by increasing the diameter of the blood vessels (independently of any change in blood flow), BP will be caused to fall. However, the oscillations caused by this loop will probably be slower than 10 seconds. The reason for this is the length of time it takes for the vessels to dilate. Although the HR component in the HR biofeedback occurs immediately, changes in vascular tone do not. Thus, the vascular tone baroreflex loop must have slower frequency characteristics than the HR baroreflex loop has.

There is very little research on this loop. One reason is the difficulty in measuring vascular tone noninvasively. A reasonable approximation of this may be pulse transit time, but validation of this measure will require a good deal of additional research.

We have found that BP resonates at about three times/minute (.03 Hz). Perhaps this reflects activity of the vascular tone baroreflex. We do not yet know.

Suppose that the vascular tone baroreflex does have resonance at about three times a minute. This means that we should be able to stimulate the system by biofeedback and by other methods of stimulation, at about three times/minute, and achieve effects similar to those achieved with HRV biofeedback. However, although the theoretical effects of stimulating the two loops are equivalent (i.e., causing large oscillations in HR and BP, overshadowing all other sources of oscillation, and stimulating the vascular tone baroreflex), the practical effects might be very different. Suppose that the person has a problem of vascular insufficiency or rigidity. Might we be able to reverse this by specifically targeting a mechanism? Perhaps targeting specific disorders with the most powerfully of biofeedback methods for that disorder might ultimately yield still larger clinical results.

**Conclusion**

HRV biofeedback is a powerful new biofeedback tool. Its effects are mediated by resonant properties in the baroreflex system that can be stimulated by breathing at the particular resonant frequency characterizing each individual. This frequency can be detected as the respiratory frequency yielding the highest amplitude of HRV. Similar effects may

be produced by other methods of rhythmic stimulation of the baroreflex system. We have found that stimulating the HR baroreflex system at its resonant frequency produces very high-amplitude HR oscillations, augments baroreflex gain, and produces multiple salutary effects. Although resonance is usually stimulated by respiration, we believe that other methods that stimulate resonant HR oscillations also might prove to be useful. We also believe that research on stimulating the vascular tone baroreflex at its slower resonant frequency will produce other important therapeutic effects.



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