ORIGINAL RESEARCH

CARDIAC COHERENCE: A NEW, NONINVASIVE MEASURE OF AUTONOMIC NERVOUS SYSTEM ORDER

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Although cardiac sympathovagal regulation has been studied during stress using power spectral density analysis of heart rate variability, little is known about its regulation during emotional states. Using heart rate variability measurements, we studied autonomic balance in 20 subjects trained in a mental and emotional self-management technique called Freeze-Frame. The study was conducted in two environments: under controlled laboratory conditions, and under real-life stressful conditions in the workplace. Power spectral density plots of R-R intervals obtained from electrocardiogram recordings were divided into three regions: low frequency (predominantly sympathetic activity), midfrequency, and high frequency (parasympathetic activity). Measurements were taken for a 5-minute baseline period, followed by a 5-minute period of positive emotional expression.

Three unique conditions of autonomic nervous system order can be clearly discriminated in the data: (1) normal heart function mode, (2) entrainment mode, and (3) internal coherence mode. The internal coherence mode is new to the electrophysiology literature. We provide supporting data for modes 2 and 3 and show that a group of 20 subjects trained in this technique can enter and maintain these states at will. We found that, when one is in the entrainment mode, other physiological systems lock to the entrainment frequency, which is approximately 0.1 Hz.

The results suggest that emotional experiences play a role in determining sympathovagal balance independent of heart rate and respiration and further suggest that positive emotions lead to alterations in heart rate variability that may be beneficial in the treatment of hypertension and reduce the likelihood of sudden death in patients with congestive heart failure and coronary artery disease. (Alternative Therapies in Health and Medicine. 1996;2(1):52-65.)

With the assistance of computers it has become apparent that heart rate variability (HRV), as measured by the beat-to-beat variation in R-R intervals of heart beats recorded by electrocardiogram (ECG), is an important physiological parameter.[1-5] The mathematical transformation of HRV into power spectral density is commonly used as a noninvasive test of integrated neurocardiac function because it can distinguish sympathetic from parasympathetic regulation of the heart rate.[6] Thus, HRV analysis provides a window through which autonomic nervous system functions can be monitored. It is commonly used to monitor and predict cardiovascular diseases[7-9] and enables the clinician to predict the development of diabetic autonomic neuropathy sooner than with other available methods.[10] It is well known that lowered HRV is associated with aging,[11] lowered autonomically mediated hormonal responses,[12] and increased incidence of sudden death.[11]

Recent work has also suggested that HRV analysis can be used to characterize psychologically based illnesses such as major depression,[13] panic disorders,[14] and anxiety and worry.[15] HRV analysis has also shown that during mental or emotional stress sympathetic activity increases and parasympathetic activity decreases.[16-18] Using power spectral density analysis, we have shown that recall of anger significantly increased sympathetic outflow to the heart, whereas feelings of appreciation decreased sympathetic and increased parasympathetic outflow.[19] Increased sympathetic activity is associated with a lower ventricular fibrillation threshold and an increased risk of fibrillation,[20] in contrast to increased parasympathetic activity, which protects the heart.[21] Decreased parasympathetic tone has been reported after acute myocardial infarction,[22] hypertension,[8] and heart failure.[23] These findings may explain why mental and emotional stress are associated with the risk of cardiac death after acute myocardial infarction[24] and may be associated with the development of hypertension.[25,26]

Interventions that enable one to increase self-control of mental and emotional states, thereby altering sympathovagal balance by decreasing sympathetic activity and increasing parasympathetic activity, could significantly influence the incidence and severity of cardiovascular disease. Recent experimental data supporting this hypothesis demonstrates that rehabilitation programs aimed at decreasing emotional distress and sympathetic arousal and improving mood can significantly reduce the long-term risk of cardiac mortality.[27,28] It has also been shown that people who express positive emotions show less life stress[29] and are less likely to become ill.[30] In the present study we assessed sympathovagal balance, using power spectral density analysis of HRV, in a group of 20 subjects trained in a stress management technique called Freeze-Frame[31] in two settings: (1) in the laboratory under controlled conditions and (2) in the workplace during real-life stressful events.

The Freeze-Frame technique has been shown to consistently produce desired shifts in parasympathetic tone and sympathovagal balance, and has been tested in both normal individuals and subjects with pathological conditions.[19,32] The technique has been employed successfully in a number of applications to reduce stress and emotional reactivity. Subjects using this technique are instructed to consciously disengage from unpleasant mental and emotional reactions, shift attention to the heart, and focus on feeling appreciation or a similar positive emotion toward someone. This 1-minute, 5-step technique, intended to be used when one is feeling stressed or out of balance, involves the following abbreviated steps:

1. Recognize the stressful feeling, and Freeze-Frame it (take a time out).
2. Make a sincere effort to shift your focus away from the racing mind or disturbed emotions to the area around your heart.
3. Recall a positive, fun feeling or time and attempt to re-experience it.
4. Using your intuition, common sense, and sincerity, ask your heart what a more efficient response to the situation would be, one that would minimize future stress.
5. Listen to what your heart says in answer to your question.

Subjects are to feel the feeling, in contrast to mentally recalling or visualizing a past positive experience. The technique is described in more detail by Childre.[31]

BACKGROUND

Figure 1A illustrates how the sympathetic and parasympathetic branches of the autonomic nervous system influence the sinus node of the heart, thereby modulating heart rate. The baroreceptor feedback system, which sends rate and blood pressure information back to the brain, is also shown in this diagram. Figure 1B illustrates the power spectrum of a 5-minute HRV waveform. The HRV power spectrum has been divided into three frequency ranges: low-frequency (LF: 0.01–0.05 Hz), mid-frequency (MF: 0.05–0.15 Hz), and high frequency (HF: 0.15–0.5 Hz).[1] The ratio of HF to LF power is often used as an approximation of sympathovagal balance. The MF region is used to discriminate the power in the baroreceptor feedback loop, which is responsible for beat-to-beat blood pressure control.[33] The power in the MF region can be due to parasympathetic or sympathetic activity, or to a mixture of both, but is primarily from parasympathetic activity.[1,34]

Mental and emotional states affect autonomic nervous system activity, HRV waveforms, and coupling between respiration and the heart: states of agitation—for instance, frustration and anger—tend to cause disorder in HRV waveforms.[35-37] Typical HRV waveforms obtained in previous studies in our laboratory are illustrated in Figures 2A and B. The top graphs are the baseline or normal state HRV waveforms and power spectral density plots, whereas the "disordered" examples show changes in a subject feeling anger. Note the jerky pattern seen in this waveform.

Although the detrimental effects of negative emotional states on cardiovascular function are well recognized, the possible beneficial effects of positive emotional states have not been well studied. Research in our laboratory has focused on the cardiovascular effects of such positive emotional states as care and appreciation, using the Freeze-Frame technique.[31] In describing these inner states and their concomitant electrophysiological changes, we have introduced several terms to the literature (see Glossary of New Terminology).

Typical HRV patterns are generated when subjects use the Freeze-Frame technique to consciously shift their inner state to one of sincere appreciation (entrainment: Figure 2) or to a state

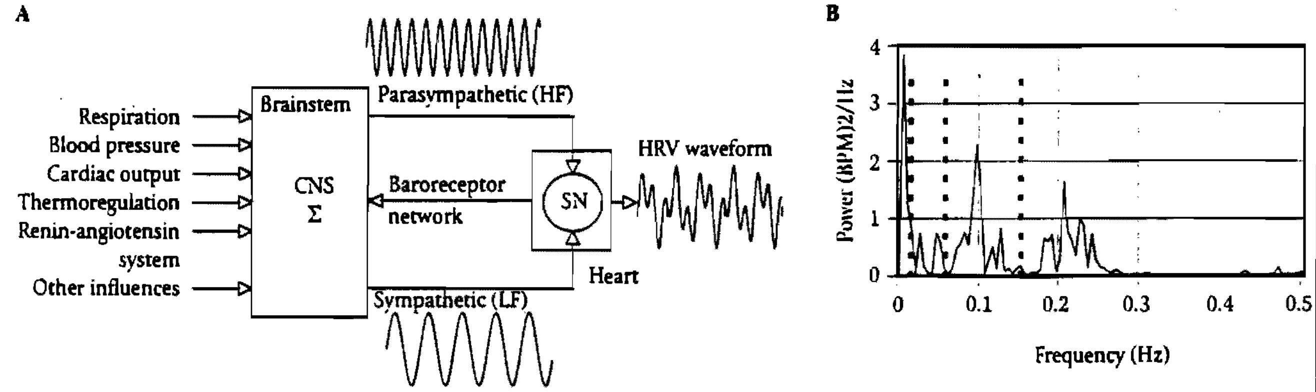

FIGURE 1 A, Power in the low-frequency (LF) region indicates mostly sympathetic activity with some hormonal influence on HRV: in the mid-frequency (MF) region power can be influenced by either sympathetic or parasympathetic activity but is predominantly parasympathetic, whereas in the high-frequency (HF) region it is only a result of parasympathetic influence on HRV. The MF region around the 0.10 Hz region is often referred to as the baroreceptor band, because it reflects the blood pressure control feedback signals sent to the brain. B shows a typical power spectrum of the HRV waveform. Σ, sum of inputs: SN, sinus node.

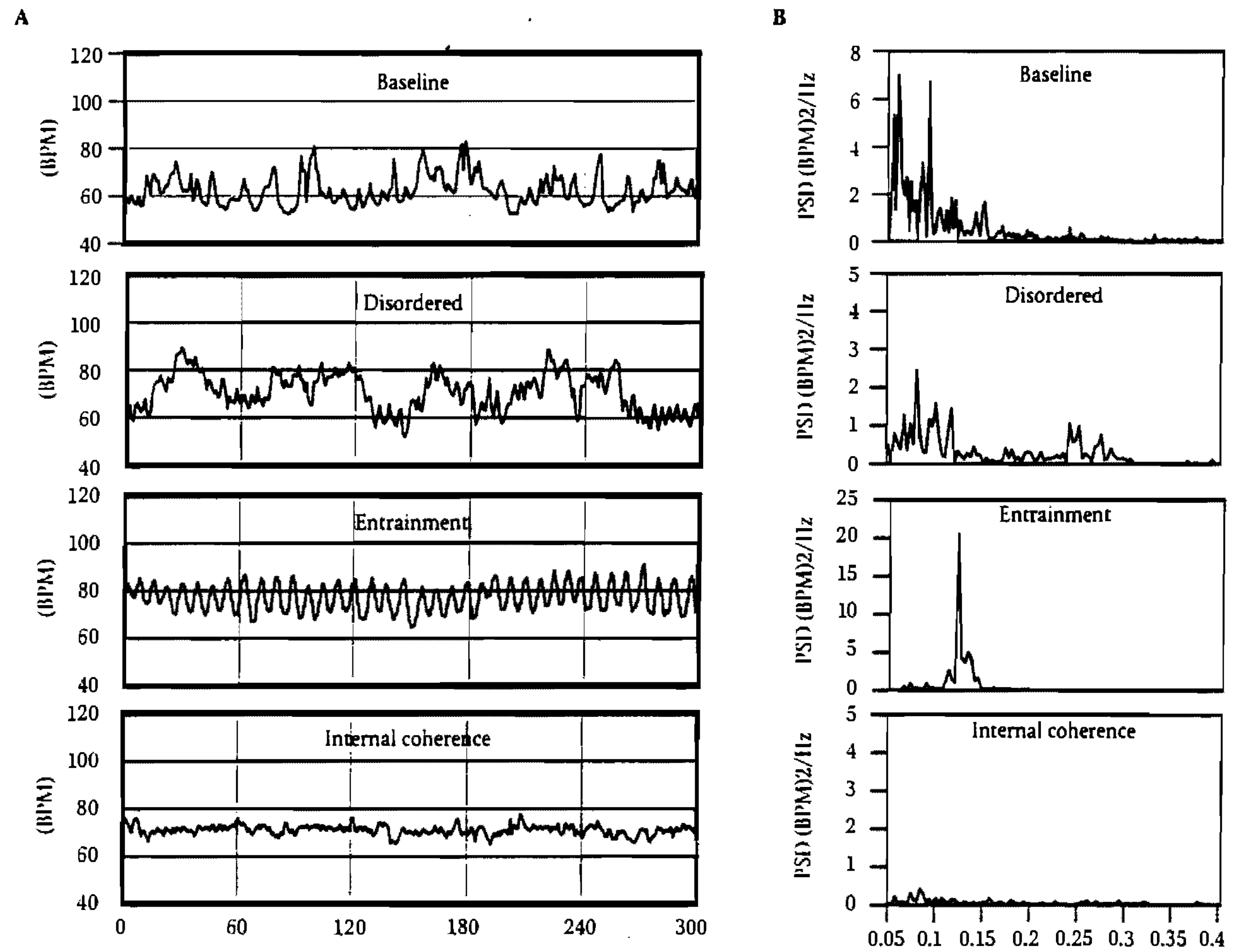

FIGURE 2 A, HRV graphs of heart function modes derived from Figure 3a ECG data; B, the corresponding power spectral density for each mode (note the scale change for the entrainment mode).

we call "amplified peace" (internal coherence). These terms characterize the mental and emotional state an individual experiences, whereas the graphs represent the electrophysiological measurement of what we call heart function modes.

Two qualitatively distinct physiological modes of heart function can be recognized by their HRV waveforms. The entrainment mode is reached when frequency locking occurs between the HRV waveform and other biological oscillators.[38,39] An example of entrainment between the HRV waveform, pulse transit time, and respiration is shown in Figure 3. In general, we have found that sincerely experienced positive emotional states such as appreciation, care, and love lead to the entrainment mode. The internal coherence mode results when one is able to shift intentionally into an inner state we have termed amplified peace. In this state one's internal mental and emotional dialog is largely reduced and one becomes aware of an inner electrical equilibrium (see Glossary of New Terminology).

The data indicate that in this state the sympathetic and parasympathetic outflow from the brain to the heart is reduced to such a degree that the oscillations in the HRV waveform become nearly zero. The frequency domain (amplitude) spectra of 10-second epochs of the ECG then exhibits a harmonic series (Figure 4B). Many of the remarkable qualities associated with this state are described by Paddison.[40]

Figure 4A presents 10-second epochs of the ECG data for the heart function modes associated with the inner feeling states of Figure 2. The states of frustration, sincere appreciation, and amplified peace yield the disordered, entrained, and internal coherence modes of heart function, respectively, compared with baseline. Figure 4B provides the corresponding amplitude spectra of this ECG data. Note the similarities in the time domains of the three ECGs compared with the Fourier analysis of the same ECG data. In particular, the presence of the internal coherence mode is clearly identified by its "clean" harmonic spectrum of standing waves. The HRV waveforms in Figure 2A are derived from 5 minutes of this same ECG data.

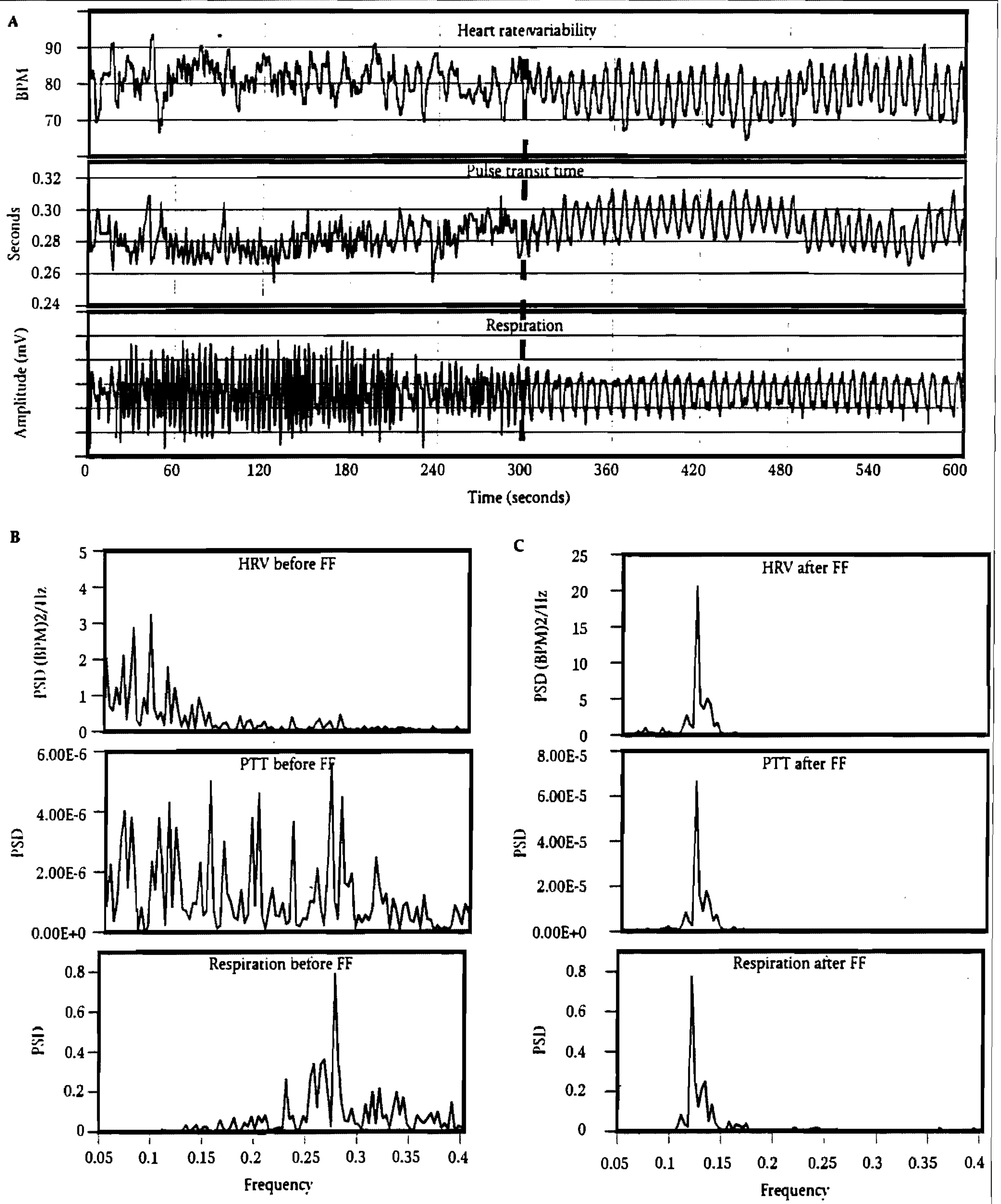

FIGURE 3 Three simultaneously recorded body information channel responses to this subject enacting a Freeze-Frame (FF) and shifting to a state of sincere appreciation at around 300 sec. A, real-time data for HRV, pulse transit time (PTT) and respiration. B, power spectra for the before-FF condition. C, power spectra for the after-FF condition.

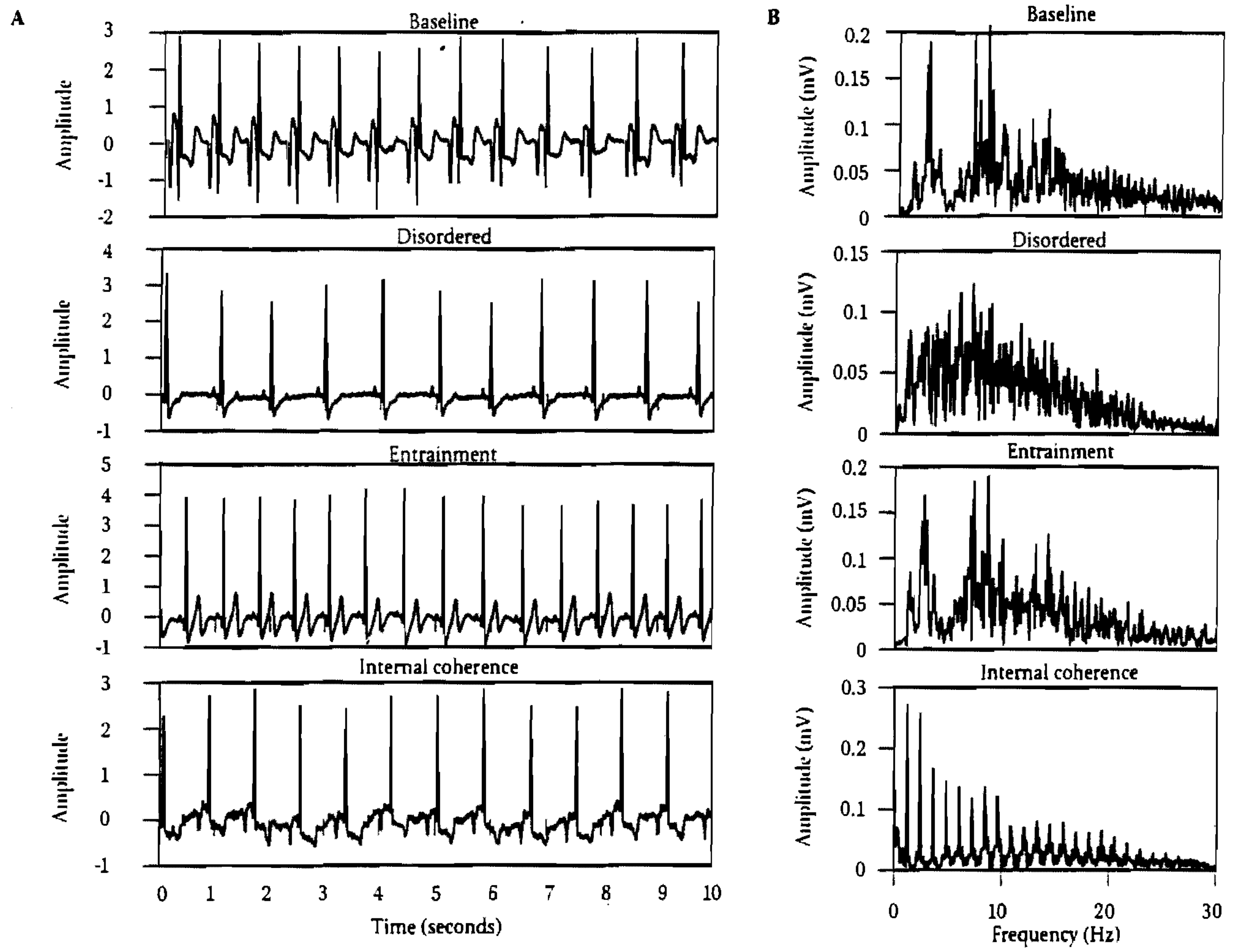

FIGURE 4 A, ECG recordings of heart function mode for subjects in four feeling states. From top to bottom, these are baseline, frustration, appreciation and amplified peace. B, Corresponding amplitude spectra for the ECG associated with each feeling state.

METHODS

Experimental Protocol

For the laboratory study 20 subjects trained in the Freeze-Frame technique were seated in straight, high-backed chairs to minimize postural changes, fitted with ECG electrodes, and then given a 10-minute rest period. ECG measurements were recorded during the rest period, and the last 5 minutes were used as the baseline period. Recordings were continued while the subjects were asked to use the Freeze-Frame technique and consciously focus on a loving state for the next 5 minutes. Five subjects were assessed at each session. A total of four sessions were conducted at the same time of day (11 AM) over 1 week. After informed consent was obtained, and before each session, subjects were asked to refrain from talking, falling asleep, and exaggerated body movements, and from intentionally altering their respiration pattern. Subjects were carefully monitored to preclude exaggerated respiratory or postural changes during the session. No biofeedback aids were used and, in fact, few if any of the subjects had prior experience with biofeedback training.

The same 20 subjects were asked to wear three-channel Holter recorders for a 24-hour period, which included a normal business day in their workplace. They were asked to use the Freeze-Frame technique on at least three occasions when they were feeling stress or were out of balance. They were instructed to press the recorder's marker button each time they used the Freeze-Frame technique. This portion of the study was designed to assess autonomic nervous system balance in a real-life stressful environment and to determine the efficacy of the Freeze-Frame technique to consciously improve sympathovagal balance. Of course, no 10-minute rest period occurred before the use of the Freeze-Frame technique in this experiment, nor was control for postural changes possible.

Physiological Measures

Disposable electrodes (silver/silver chloride) were used for all bipolar ECG measurements. The positive electrode was placed on the left side at the sixth rib, and the reference was placed in the right supraclavicular fossa. Amplifiers (model 7P4; Grass Instrument Co, Quincy, Mass) were used for ECG amplification. Respiration was monitored with a piezoelectric belt (Resp-EZ; EPM Systems, Midlothian, Va) around the chest. A cardiac microphone (model 80; Grass Instrument Co) was used to record the blood pressure wave for calculation of pulse transit time (the interval between the peak of the R wave and appearance of the pulse wave associated with that same cardiac contraction at the index finger on the left hand). In the workplace study, the ambulatory ECG was recorded with a Holter recording system (model 363; Del Mar Avionics, Irvine, Calif).

Data Analysis

The HRV waveform is in the form of an R-R interval tachogram. The spectral analysis of this signal was obtained from the successive discrete series of R-R duration values taken from the ECG signal sampled at 256 Hz and transformed by the Fast Fourier technique.[2] All data from the laboratory study were digitized by a BioPac 16-bit digitizer and software system.[41] All postanalysis, including Fast Fourier Transforms (FFT), power spectral density, and time domain measurements, was done with digital signal processing software.[42] A total of 51 Freeze-Frame responses from the Holter tape data were artifact-free and used for analysis.

For the laboratory study HRV data were analyzed for 5 minutes before and 5 minutes during practice of the Freeze-Frame technique. The time domain traces were analyzed by obtaining the overall mean heart rate for both 5-minute periods and calculating the standard deviation around that mean. FFTs of the time domain data were analyzed by dividing the power spectra into three frequency regions: LF (0.01–0.05 Hz), MF (0.05–0.15 Hz) and HF (0.15–0.5 Hz). The integral of the total power in each of these regions, the total power over all regions (LF+MF+HF), the LF/HF ratio, and the MF/(LF+HF) ratio were calculated for each subject in the baseline and Freeze-Frame periods. The following criteria were used to classify the subjects into two subgroups. (Subgroup classification was done only for the laboratory studies.)

Entrainment Mode

A very narrow-band, high-amplitude signal in the MF region of the HRV power spectrum, with no other peaks in the LF or HF region, and a relatively harmonic signal (sine wavelike), in the time domain trace of the HRV data, were used to identify the entrainment mode as illustrated in Figures 2A and 2B. These parameters were used as the criteria to assign subjects to the entrainment group in this study. We previously confirmed that the above criteria used to define the entrainment mode are adequate by also examining the frequency locking between HRV respiration and pulse transit time.[17] Figure 3 is a typical example of such frequency-locking in the entrainment mode.

Internal Coherence Mode

The internal coherence mode is identified by an intentionally produced very low amplitude signal across the entire HRV power spectrum compared with the baseline. The final discriminator of this mode is the ECG amplitude spectrum as shown in the bottom panel of Figure 4B. Here, one sees the first seven or so harmonics of the fundamental frequency clearly displayed with very few intermediate frequencies having a significant amplitude. Figure 5 illustrates the conscious transition of a subject from the entrainment to the internal coherence mode.

Statistical Analysis

The raw data baseline values to emotional expression values were analyzed for significance by using the Wilcoxon Signed Rank Test (T) using the sum of the ranks for positive and negative differences for each group. Wilcoxon *P* values were taken from the table of critical values for the Wilcoxon Signed Rank Test (T). The Wilcoxon T and W values are reported in the appropriate tables.

RESULTS

Table 1 provides time domain and spectral analysis data for the 20 subjects. When the group was analyzed as a whole, there was no change in heart rate or heart rate standard deviation during the Freeze-Frame period. The power spectral analysis showed a significant decrease in the LF/HF ratio and significant increases in MF power ($P<.01$), HF power ($P<.01$) and in the MF/(LF+HF) ratio ($P<.01$).

Figure 6A shows representative heart rate tachograms of the baseline and Freeze-Frame periods for five subjects from the laboratory study; Figure 6B shows the corresponding power

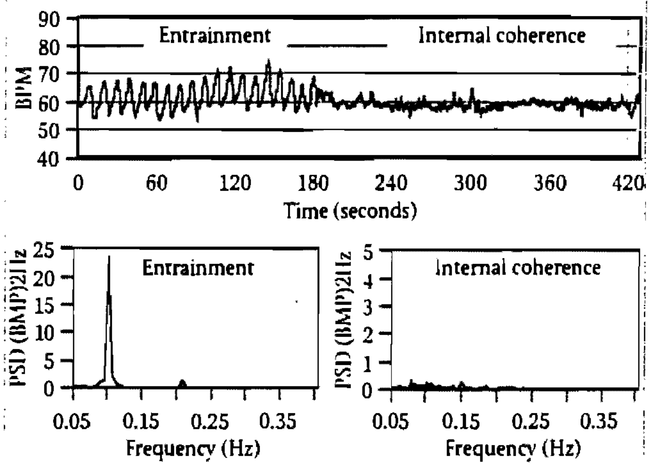

FIGURE 5 Illustration of a subject's intentional shifting from the entrainment mode to the internal coherence mode. The top graph illustrates the change in the HRV waveform; below are power spectra of the entrained mode and internal coherence mode. Note the large difference in scale between the two spectra.

TABLE 1 Cardiovascular characteristics for the laboratory study group

Variable	Baseline	Baseline SD	During FF	SD during FF	(W)	(T)	*P*
LF	0.057	0.036	0.034	0.022	-92	59	NS
MF	0.070	0.033	0.218	0.228	156	27	.01
HF	0.025	0.014	0.039	0.023	158	26	.01
Total power	0.152	0.067	0.290	0.254	126	42	.02
LF/HF	2.905	2.232	1.669	3.404	-146	32	.01
MF/(LF+HF)	0.980	0.477	2.818	2.295	174	18	.01
Heart rate	81.495	11.278	80.313	10.85	-84	63	NS
Heart rate SD	5.213	1.13	6.267	2.56	98	56	NS

NS, not significant; T, the smaller number obtained from either the positive or negative sum of signed ranks; W, sum of signed ranks.

spectrum data. Note the large difference in the ordinate scale for subjects 5 and 9 in Figure 6B. Unlike the other three individuals, subjects 6 and 8 do not show a clearly defined peak in the MF region. These results show the development of two patterns of autonomic nervous system activity after the use of the Freeze-Frame technique. Based on the criteria described in the background section, sixteen of the subjects were assigned to an entrainment mode subgroup and four to the internal coherence mode subgroup for further analysis. The mean heart rate and heart rate standard deviation (SD) values for the subgroups are presented in Tables 2 and 3 for the baseline and Freeze-Frame periods. When analyzed separately, heart rate following the Freeze-Frame period did not reach significance in either subgroup. However, the two subgroups could be distinguished by heart rate SD values. The heart rate SD of the entrainment group increased significantly ($P<.01$), but in the internal coherence group it decreased. Because of the small number of subjects in this group, however, meaningful statistics could not be derived.

Spectral analysis of the HRV data for the laboratory subjects is also presented in Table 2. The group mean spectral data are presented graphically in Figure 7 for both subgroups. The results for the entrainment subgroup indicate that during the Freeze-Frame period HF power increased significantly ($P<.01$) and total power ($P<.01$) more than doubled. In addition, activity in the MF region increased significantly during the Freeze-Frame period, whether expressed as the total power in this region ($P<.01$) or as the MF/(LF+HF) ratio ($P<.01$) (Figure 8A). This increase in MF activity observed in the entrainment subgroup is clearly shown in the average power spectra in Figure 7. The results in Table 3 and Figure 8B for the internal coherence subgroup indicate a decrease in the MF frequency band, whether expressed as the total power in this region or as the MF/(LF+HF) ratio. A clear decrease in LF and total power can be seen in the average power spectra shown in Figure 7.

Through qualitative analysis of the ECG amplitude spectra for these four subjects it could be seen that they had only partially developed the internal coherence mode of heart function. Recalling the internal coherence mode on Figure 4B, the first seven or so harmonics of the fundamental frequency are clearly displayed, with few intermediate frequencies having a significant amplitude. If we define this as approximately 100% internal coherence mode, then the four subgroup members had only partially expressed this mode because a variety of intermediate frequencies of significant amplitude appeared in their ECG amplitude spectra after the third to fourth harmonic of the fundamental frequency (data not shown).

Figure 9A shows representative heart rate tachogram waveforms for the baseline and Freeze-Frame periods from five subjects at the workplace; Figure 9B shows the corresponding power spectrum data. In this section of the study, we chose not to separate the subjects into subgroups. Mean data of the group is presented in Figures 10 and 11 and Table 4. The results from this study were similar to those obtained in the laboratory study. There was a significant reduction in LF power ($P<.01$) and a significant increase in both MF ($P<.05$) and HF power ($P<.01$). The LF/HF ratio was also significantly reduced ($P<.01$) and the MF/(LF+HF) ratio was significantly increased ($P<.01$).

DISCUSSION

In the last 25 years a variety of techniques have been introduced as alternatives to traditional psychotherapeutic or pharmaceutical interventions for mental or emotional imbalances. In addition to psychological approaches such as cognitive restructuring and neurolinguistic programming, psychologists have employed several techniques from Eastern cultures to "still the mind" during focused meditation. In yoga, for example, one generally focuses on the breath or parts of the brain, whereas in qigong one focuses on the *dan tien* point (below the navel). In the Freeze-Frame technique used in this study, on the other hand, one focuses on the area around the heart. The above techniques focus attention on areas of the body that are known to contain biological oscillators. The heart, brain, and intestines[43] contain biological oscillators known as pacemaker cells. By intentionally focusing attention on one of these oscillator systems, the subject

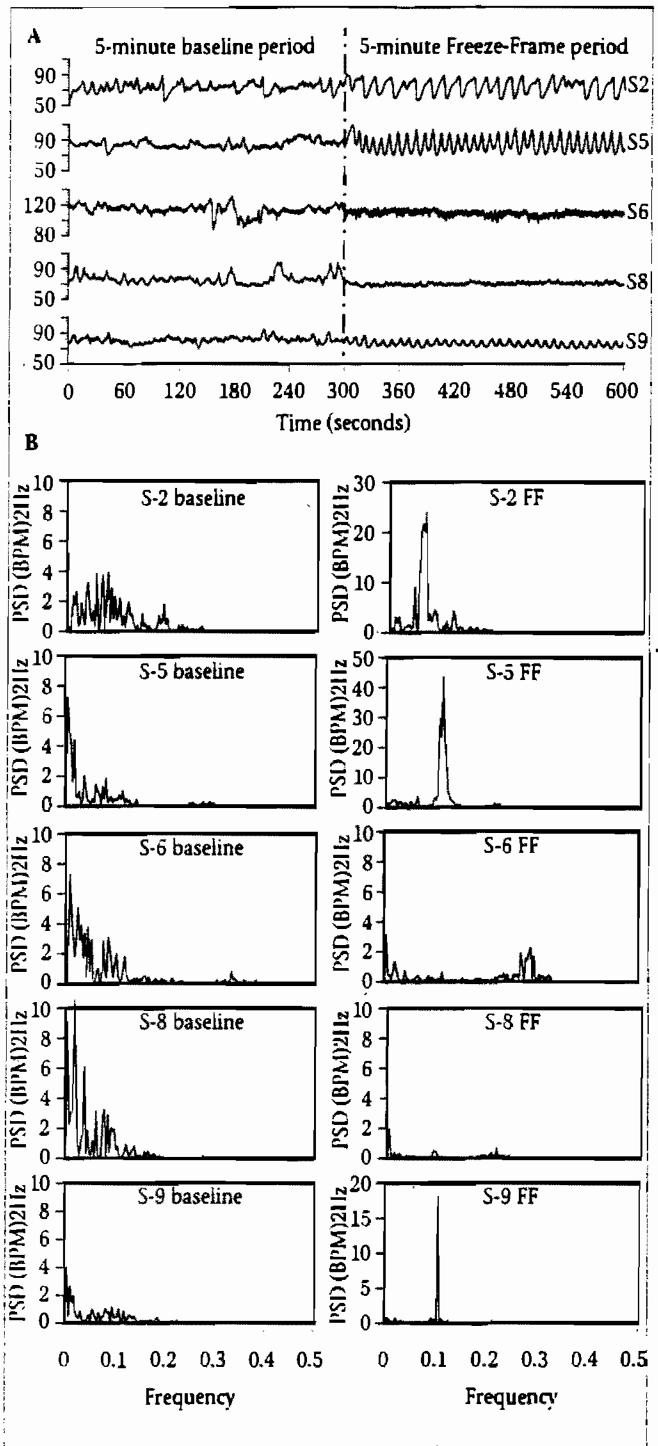

FIGURE 6 A representative sample from the laboratory study. A, real-time HRV data for subjects 2, 5, 6, 8, and 9 before and after the Freeze-Frame intervention. B, corresponding HRV power spectra. Note the large difference in ordinate scales for subject 5.

can alter its rhythms. This is true at least for the brain (meditation), yogic breathing (respiration), and the heart (Freeze-Frame), and is most likely true in the case of the gut (qigong), which is also regulated by the autonomic nervous system. The body also contains other oscillating systems such as the smooth muscles of the vascular system.[33] We have previously shown that this system, measured by recording pulse transit time, as well as the brain (EEG), the heart (HRV), and respiration rate can all entrain.[37] Furthermore, they all synchronize to a frequency varying around 0.1 Hz (Figure 3). Thus, we can intentionally bring these systems, acting as coupled electrical oscillators, in synchrony with each other.

The Freeze-Frame technique, used in this study, is a self-management technique by which one focuses on the heart to disengage from moment-to-moment mental and emotional reactions. In a previous study of 24 HIV-positive subjects[44] trained to use the Freeze-Frame technique in a psychological intervention program, significant reductions were found in life stress, state and trait anxiety levels, and self-assessed physical symptoms. In two other studies with healthy subjects using the Freeze-Frame technique to enhance positive emotional states, salivary IgA[32] and sympathovagal balance increased.[19] Increased sympathovagal balance is known to protect against detrimental physiological effects associated with overactive sympathetic outflow from the brain.[21]

Sympathovagal balance has also been measured using other techniques. For example, individuals can be trained to control their heart rate using biofeedback techniques.[45] However, the enhanced parasympathetic activity is probably mediated through control of respiration.[38] Neutral hypnosis[46] and operant conditioning of heart rate[47] have been demonstrated to decrease the sympathetic/parasympathetic ratio by increasing parasympathetic activity independent of controlled breathing techniques. The Freeze-Frame technique does not require biofeedback equipment nor conscious control of respiration. Our results suggest that emotional experiences play a role in determining sympathovagal balance independent of heart rate and respiration. The shifts in sympathovagal balance toward increased MF and HF power were physiological manifestations of the subject's emotional state of appreciation. The Freeze-Frame technique focuses on experiencing the sincere feeling of appreciation or love, in contrast to visualizing or recalling a positive emotional experience.

The results of the present study indicate that relatively short periods of practice of the Freeze-Frame technique lead to either the entrainment or internal coherence mode of heart function. Most subjects who are able to maintain these states report that the intrusion of random thoughts is greatly reduced and that the state is accompanied by feelings of deep inner peace and heightened intuitive awareness.

We also observed that positive emotional states, which lead to the entrainment mode, generated a marked increase in MF power. The choice of the cutoff point between the LF and MF regions is not standardized but is set at varying points by different investigators, often around 0.08 Hz. We chose a 0.05-Hz cutoff, because the parasympathetic system can operate down to, and in

TABLE 2 Cardiovascular characteristics for the entrainment subgroup from the laboratory study

Variable	Baseline	Baseline SD	During FF	SD during FF	(W)	(T)	*P*
LF	0.053	0.032	0.039	0.021	-40	48	NS
MF	0.071	0.035	0.269	0.228	136	0	<.01
HF	0.026	0.014	0.039	0.024	100	18	<.01
Total power	0.149	0.066	0.347	0.253	128	4	<.01
LF/HF	2.748	2.261	1.937	3.773	86	25	<.05
MF/(LF+HF)	1.036	0.511	3.456	2.121	136	0	<.01
Heart rate	80.812	7.935	80.038	7.901	-38	49	NS
Heart rate SD	5.183	1.050	7.001	2.294	110	13	<.01

NS, not significant; T, the smaller number obtained from either the positive or negative sum of signed ranks; W, sum of signed ranks.

TABLE 3 Cardiovascular characteristics of the internal coherence subgroup from the laboratory study

Variable	Baseline	Baseline SD	During FF	SD during FF
LF	0.077	0.051	0.016	0.012
MF	0.066	0.025	0.011	0.002
HF	0.022	0.011	0.035	0.026
Total power	0.166	0.081	0.062	0.031
LF/HF	3.532	2.307	0.596	0.558
MF/(LF+HF)	0.754	0.225	0.265	0.145
Heart rate	84.227	21.860	81.412	20.779
Heart rate SD	5.330	1.602	3.333	0.834

some cases below, this point.[48] If we had chosen a higher frequency, the data could have been misinterpreted as only sympathetic activity. Therefore, in order to determine which of the autonomic nervous system branches is pumping power into the MF region, both respiration and pulse transit time must be recorded simultaneously.

Although mechanisms were not examined, we believe that this increase in MF power in the entrainment mode represents increased afferent activity of baroreceptors. This idea is supported by the work of Robbe et al,[49] who have shown that the MF

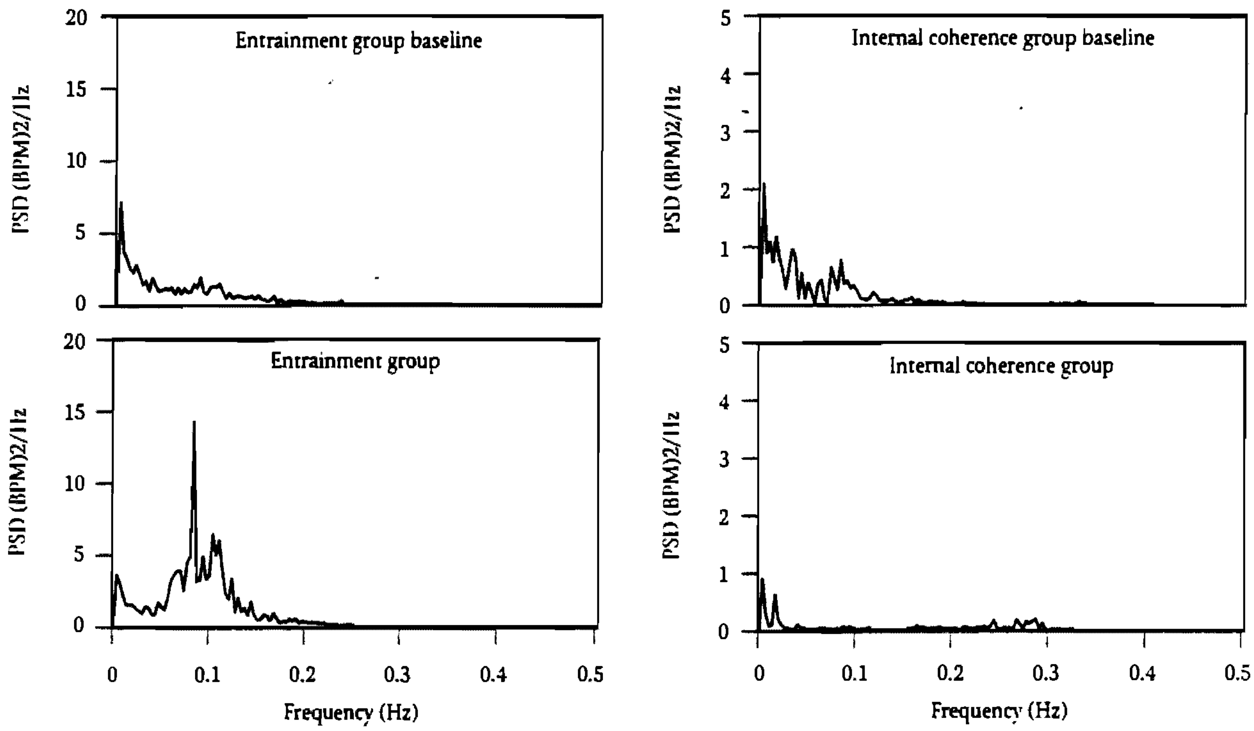

FIGURE 7 Mean power spectra before (baseline) and after the FF intervention for the entrainment subgroup (left) and the internal coherence subgroup (right).

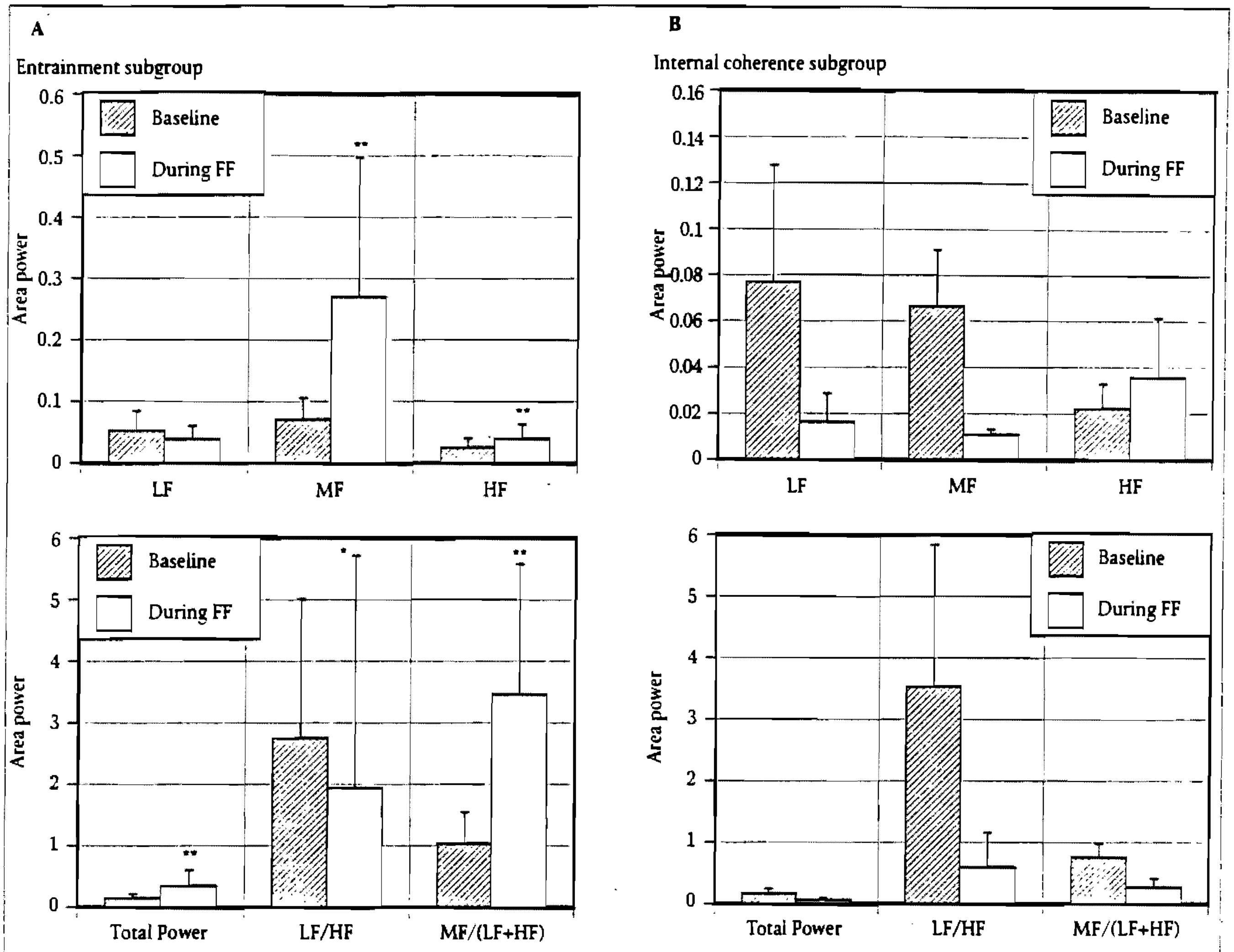

FIGURE 8 Group mean integral power and total power across all frequency bands for the entrainment subgroup (A) and the internal coherence subgroup (B). * $P < .05$; ** $P < .01$.

band reflects baroreceptor reflex sensitivity and is affected by physiological states. Baroreceptor activity is known to inhibit sympathetic outflow from the brain to peripheral vascular beds,[50-53] whereas stress increases sympathetic outflow and inhibits baroreflex activity.[54] The increase in MF power during appreciation may have important implications for the control of hypertension, because baroreflex sensitivity is reduced in these subjects.[55-57]

In Figure 9 (from the workplace study) the transition is obvious after the Freeze-Frame intervention to either the entrainment mode or near internal coherence mode by means of the HRV waveforms and power spectral density data. In addition, some of the subjects reported that they were able to use the Freeze-Frame technique while they were in a tense conversation and starting to react. Even during these conditions, subjects' HRV waveforms indicate that they were able to shift to and maintain the entrainment state. This conclusion is clearly supported by the data in Figures 10 and 11.

From the tachogram data of Figure 2A it can be seen that, as one moves from a state of frustration to one of sincere appreciation to amplified peace, a transition occurs in the waveforms from a noisy wave of large amplitude to a harmonic wave form of similar amplitude (entrainment) and then to a smaller amplitude wave (internal coherence). In Figure 2B the transition in the frequency domain (power spectral density) is from a wide-band spectrum of moderate amplitude to a narrow-band spectrum, about 0.1 Hz of very large amplitude (entrainment) and then to a wide-band spectrum of very small amplitude (internal coherence).

In untrained individuals small to near-zero HRV, as just described, is an indicator of a potentially pathological condition[11] or aging,[52] because it connotes loss of flexibility of the heart

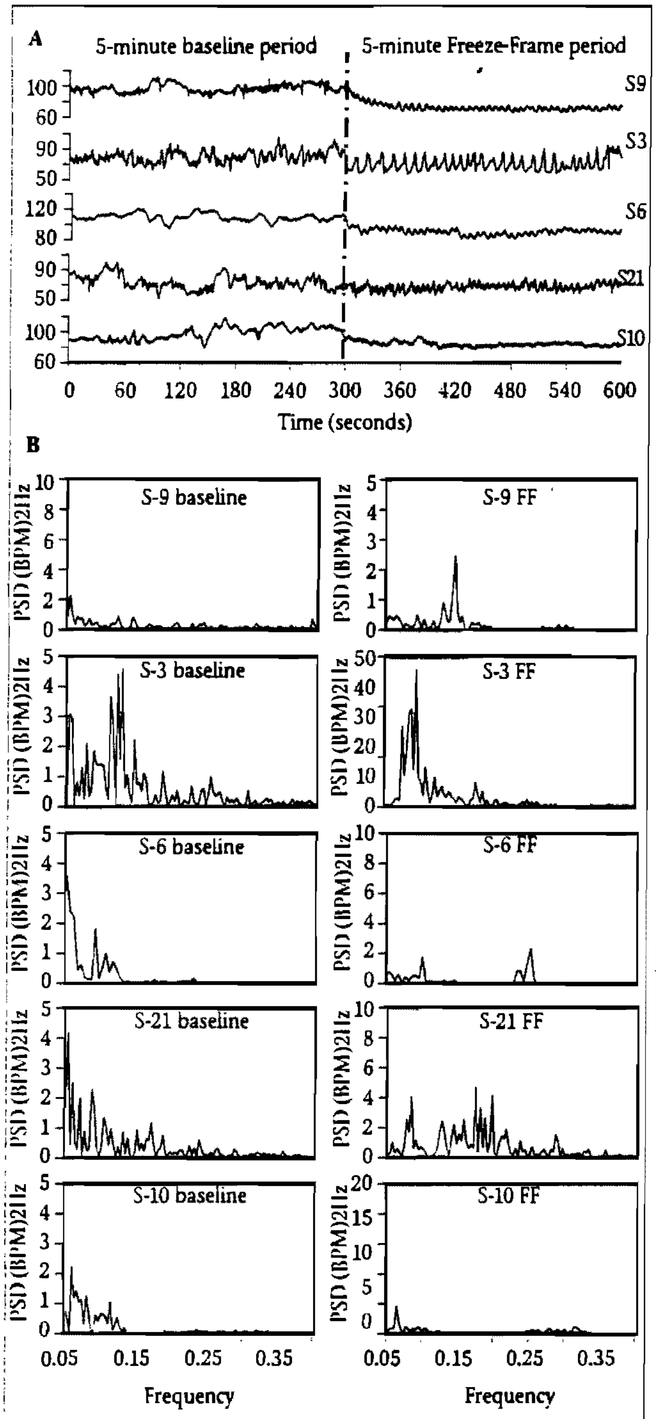

FIGURE 9 A representative sample of the workplace study A. real-time HRV data for subjects 9, 3, 6, 21, and 10 before and after the Freeze-Frame intervention. B. corresponding HRV power spectra. Note the ordinate scale changes.

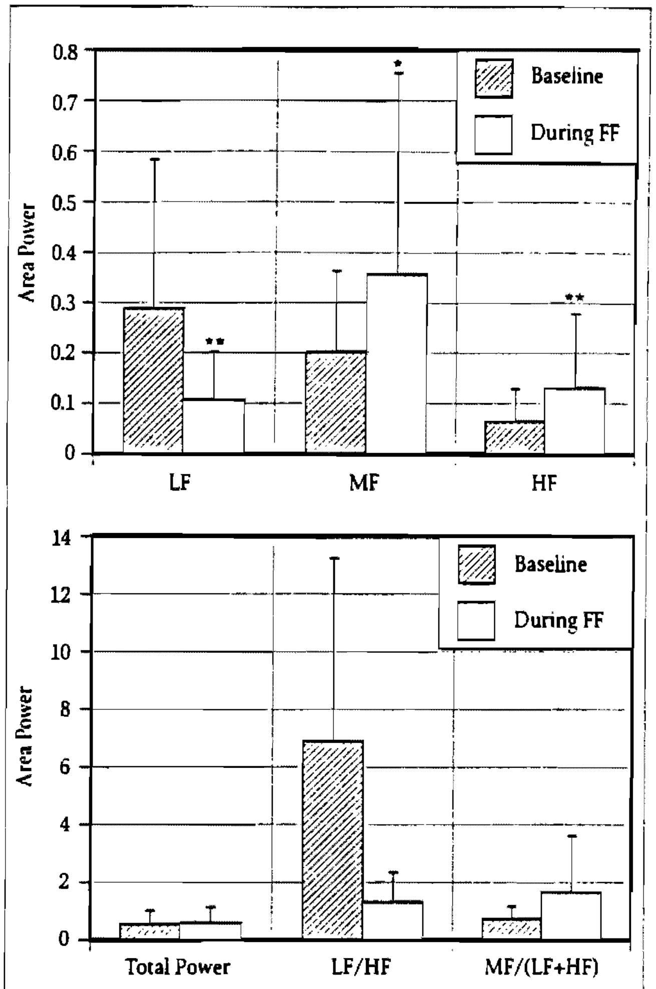

FIGURE 10 Mean integral power of group in LF, MF, HF, LF/HF and MF/(LF+HF) and total power across all frequency bands for the workplace study. * $P < .05$; ** $P < .01$.

to change in rate or decreased flow of information in the autonomic nervous system. However, in trained subjects, it is an indication of exceptional self-management because their HRV is normally large and the shift into the internal coherence mode is a result of their entering the amplified peace state. This state is different from a pathological condition underlying lowered HRV (in such cases the HRV is always low). The connection between emotional states and HRV could account for the occasional observation of low HRV in otherwise healthy individuals.[2] This observation has detracted from the clinical utility of HRV analysis for unequivocally predicting disease.

During the condition of internal coherence, the electromagnetic energy produced by the heart, as seen in the FFT analysis of the ECG signal, is a clear example of a coherent electromagnetic field. Recent advances in our understanding of the interaction between coherent signals and noise in nonlinear systems has resulted in the prediction that these nonthermal, coherent electromagnetic signals may be detected by cells.[58,59] Further evidence suggests that coherent electromagnetic fields may have important implications for cellular function. For example, it has

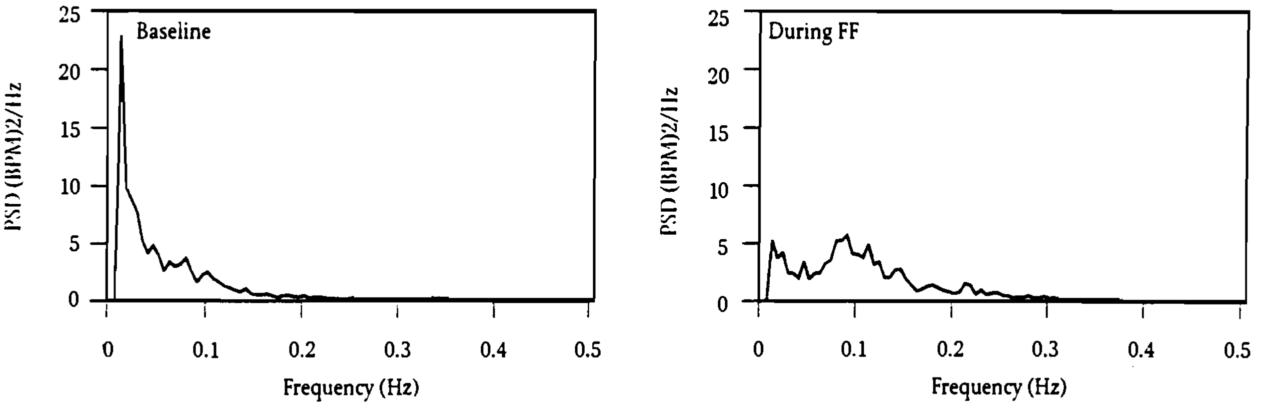

FIGURE 11 Mean power spectra before (baseline) and during the FF intervention (left) for the workplace study.

been demonstrated that nonthermal, extremely low frequency electromagnetic signals may affect intracellular calcium signaling.[60] In addition, coherent electromagnetic fields have been shown to produce substantially greater cellular effects on enzymatic pathways, such as ornithine decarboxylase activity, than do incoherent signals.[61] This fact suggests that the state of internal coherence may also affect cellular function and provides a potential link between emotional states, autonomic function, HRV, and cellular processes.

This study demonstrates that conscious focus of attention or positive emotions can significantly influence HRV and power spectral density. Although we examined only a small number of subjects over a short period of time, the results support previous work and suggest that psychological interventions that minimize negative and enhance positive emotional states could significantly influence cardiovascular function. Larger studies assessing the effects of this type of behavioral intervention and employing longer assessments of HRV are now urgently required.

CONCLUSIONS

The results of this work demonstrate that sincere feelings of appreciation produce a power spectral shift toward MF and HF activity and support other studies indicating that: (1) the major centers of the body containing biological oscillators can act as coupled electrical oscillators, (2) these oscillators can be brought into synchronized modes of operation through mental and emotional self-control, and (3) the effects on the body of such synchronization are correlated with significant shifts in perception and cardiovascular function. It is suggested that positive emotions lead to alterations in sympathovagal balance, which may be beneficial in the treatment of hypertension and reduce the likelihood of sudden death in patients with congestive heart failure and coronary artery disease.

Acknowledgment
The authors acknowledge Doc Lew Childre, founder and president of the Institute of HeartMath, for his guidance and facilitation in this project and for the creation of the Freeze-Frame technique.

TABLE 4 Cardiovascular group characteristics for the workplace study

Variable	Baseline	Baseline SD	During FF	SD during FF	(W)	(T)	*P*
LF	0.288	0.296	0.107	0.094	-1004	161	<.01
MF	0.201	0.162	0.356	0.397	492	417	.05
HF	0.064	0.065	0.131	0.148	874	226	<.01
Total power	0.553	0.456	0.594	0.543	116	605	NS
LF/HF	6.895	6.331	1.304	1.038	-1254	36	<.01
MF/(LF+HF)	0.721	0.434	1.694	1.956	782	272	<.01
Heart rate	97.348	12.805	111.443	15.803	1174	76	<.01
Heart rate SD	7.972	3.485	7.099	3.536	-462	432	<.05

NS, not significant.

Glossary of New Terminology

Fast Fourier Transform—The specific mathematical transformation of time domain data into frequency domain data. This results in a type of histogram that measures the relative amplitudes for the different frequency components (rhythmic patterns) in the time domain waveform. Fast real-time rhythms map into peaks in the high-frequency portion (right side) of the spectrum, whereas slow rhythms appear on the left, or low-frequency side. A given peak may be caused by a single rhythmic process or a mixture of rhythms with similar frequencies. The latter contribute to the height of a peak and increase its width. In the case of heart rate analysis, different frequencies (peaks) in the power spectrum are caused by cyclic fluctuations in autonomic (sympathetic and parasympathetic) activity.

Power Spectral Density (PSD)—The power spectrum of a waveform is a plot of the wave amplitude for each component squared, as a function of the frequency of that component. This plot, expressed in units of energy per hertz, is the PSD, which is the wave power present in a small frequency range, Δf, as a function of frequency, f.

Freeze-Frame©—A tool used in the HeartMath system of self-management that consists of consciously disengaging the mental and emotional reactions to either external or internal events and then shifting the center of attention from the mind and emotions to the physical area around the heart while focusing on a positive emotion such as love or appreciation. This tool thus allows the individual to shift from the mind to the heart. Such a shift results in a wider and more objective perception while stress is occurring, as opposed to after the event has taken place.

Appreciation—The state in which the subject has clear perception or recognition of the feelings of sincere or active appreciation for someone or something. It is this heart-felt feeling that is associated with the HRV changes reported in this article, as contrasted with the mental concept of appreciation, which does not appear to produce such HRV changes.

Amplified Peace—Used to distinguish an inner state in which a deeper than normal state of peace and centeredness is felt. One also has a sense of standing on the threshold of a new dimension of awareness in this state, with a sense of inner equilibrium and an awareness that one has accessed a new domain of intuition. As with any experiential state, words do not adequately describe it; also, one enters this state for relativity short periods. However, with practice at staying focused on the heart, time in this state can be increased. It may be similar to moments at the beach or in the forest when one feels an especially deep contact with nature or with oneself that is beyond one's normal experience. In such moments one may find answers to life's deeper issues or problems.

Biological Oscillators—Cells or groups of cells that produce rhythmic oscillation. When the instantaneous systemic arterial pressure is continuously recorded, fluctuations with each heart beat and breath are seen. This rhythmic activity in the autonomic nervous system appears to be supported by at least three biological oscillator systems: (1) centrogenic rhythms in brainstem networks with facultative coupling (entrainment) with the respiratory oscillator, (2) the baroreceptor feedback network, and (3) the autorhythmicity of the vascular smooth muscle.[33] The fact that each of the oscillators can develop different frequencies and that phase lags between oscillations may vary easily explains the general experience that blood pressure waves are variable and unpredictable. The existence of several oscillators with similar basic frequencies enables synchronization and entrainment between oscillators. Thus, we can assume that states of regular and steady blood pressure waves are the expression of the entrained action of the complex multioscillatory system.[33,62,63]

Arterial Pulse Transit Time—Measure of the speed of travel of the arterial pulse wave from the heart to a peripheral recording site. It is used as a noninvasive method to monitor the elasticity of artery walls and to indicate beat-to-beat changes in blood pressure. The arterial pressure pulse is a wave of pressure that passes rapidly along the arterial system. The pulse wave velocity (4–5 m/s) is much faster than the velocity of blood flow (<0.5 m/s). The pulse wave velocity varies directly with pressure-related changes in the elasticity of the arterial wall.[64] The more rigid or contracted the arterial wall, the faster the wave velocity. Therefore, it follows that pulse transit time should vary inversely with blood pressure. Common estimates of the magnitude of this effect indicate that pulse transit time varies by about 1 ms/mm Hg change in pressure.[65]

References

1. Kleiger RE, Stein PK, Bosner MS, Rottman JN. Time domain measurements of heart rate variability. *Ambul Electrocardiol.* 1992;10:487-498.
2. Ori Z, Monir G, Weiss J, Sayhouni X, Singer DH. Heart rate variability frequency domain analysis. *Amb Electrocardio.* 1992;10:499-537.
3. Pomeranz B, Macaulay JB, Caudill MA. Assessment of autonomic function in humans by heart rate spectral analysis. *Am J Physiol.* 1985;248:H151-H158.
4. Akselrod S, Gordon D, Ubel FA, Shannon DC, Barger AC, Conen RJ. Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. *Science.* 1981;213:220-222.
5. Appel ML, Berger RD, Saul P, Smith J, Cohen R. Beat to beat variability in cardiovascular variables: noise or music? *J Am Coll Cardiol.* 1989;14:1139-1148.
6. Pagani M, Lombardi F, Guzzette S. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dogs. *Circ Res.* 1986;59:178-184.
7. Kleiger RE, Miller JP. Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. *Am J Cardiol.* 1978;59:256-262.
8. Frey B, Binder T, Teutelsbauer H, et al. Heart rate variability and patient outcome in advanced heart failure. *Am J Cardiol.* 1993;21:286A. Abstract.
9. Saini MW, Kleiger RE, Carney RM, teVelde A, Freedland KE. Correlation of heart rate variability with clinical and angiographic variables and late mortality after coronary angiography. *Am J Cardiol.* 1988;62:714-717.
10. Comi G, Sora MGN, Bianchi A. Spectral analysis of short term heart rate variability in diabetic patients. *J Auton Nerv Syst.* 1990;30:S45-S50.
11. Singer DH, Martin GJ, Magid N, et al. Low heart rate variability and sudden cardiac death. *J Electrocardiol.* 1988(suppl):46-55.
12. Lovallo WR, Pincomb GA, Brackett DJ, Wilson MF. Heart rate reactivity as a predictor of neuroendocrine responses to aversive and appetitive challenges. *Psychosom Med.* 1990;52:17-26.
13. Yeragani VK, Pohl R, Balon R, et al. Heart rate variability in patients with major depression. *Psychiatr Res.* 1991;37:35-46.
14. Yeragani VK, Pohl R, Berger R, et al. Decreased HRV in panic disorder patients: a study of power-spectral analysis of heart rate. *Psychiatr Res.* 1993;46:89-103.
15. Thayer JF, Friedman BH, Borkovec TD. Autonomic characteristics of generalized anxiety disorder and worry. *Soc Biol Psychol.* 1995;37:1-11.
16. Lindqvist A, Keskinen E, Antila K, Halkola L, Peltonen T, Valimaki I. Heart rate variability, cardiac mechanics, and subjectively evaluated stress during simulator flight. *Aviat Space Environ Med.* 1983;54:685-690.
17. Kamada T, Miyake S, Kumashiro M, Monou H, Inoue K. Power spectral analysis of heart rate variability in type As and type Bs during mental workload. *Psychosom Med.*

1992;54:462-470.
18. Kollai M. Kollai B. Cardiac vagal tone in generalised anxiety disorder. *Br J Psychiatr.* 1992;161:831-835.
19. McCraty R. Atkinson M. Tiller WA, Rein G. Watkins A. The effects of emotions on short term heart rate variability using power spectrum analysis. *Am J Cardiol.* 1995;76:1089-1093.
20. Lown B. DeSilva M. Lenson R. Role of psychologic stress and autonomic nervous system changes in provocation of ventricular premature complexes. *Am J Cardiol.* 1978;41:979-985.
21. Lown B. Verrier R. Neural activity and ventricular fibrillation. *N Engl J Med.* 1976;294:1165-1172.
22. Rothschild M. Rothschild A. Pfeifer M. Temporary decrease in cardiac parasympathetic tone after acute myocardial infarction. *Am J Cardiol.* 1988:62:637-639.
23. Saul JP. Arai Y. Berger RD. Lilly LS. Colucci WS. Cohen RJ. Assessment of autonomic regulation in chronic congestive heart failure by heart rate spectral analysis. *Am J Cardiol.* 1988:61:1292-1299.
24. Shelelle RB. Vernon SW. Ostfeld AM. Personality and coronary heart disease. *Psychosom Med.* 1991:53:176-184.
25. Markovitz JH. Matthews KA. Kannel WB. Cobb JL. Psychological predictors of hypertension in the Framingham study: Is there tension in hypertension? *JAMA.* 1993;270:2439-2494.
26. Conway J. Boon N. Jones JV. Sleight P. Involvement of the baroreceptor reflex in changes in blood pressure with sleep and mental arousal. *Hypertension.* 1983;5:746-748.
27. Frasure-Smith N. In-hospital symptoms of psychological stress as predictors of long-term outcome after acute myocardial infarction in men. *Am J Cardiol.* 1991:67:121-127.
28. Dracup K. Moser DK. Marsden C. Taylor SE. Guzy PM. Effects of a multidimensional cardiopulmonary rehabilitation program on psychosocial function. *Am J Cardiol.* 1991;68:31-34.
29. Jemmott JB. Social motives and susceptibility to disease. *J Pers.* 1987;55:267-293.
30. McClelland DC. Jemmott JB. Power motivation. stress. and physical illness. *J Hum Stress.* 1980;6:6-15.
31. Childre DL. *Freeze Frame®. Fast Action Stress Relief.* Boulder Creek. Calif: Planetary Publications; 1994:132.
32. Rein G. McCraty RM. Atkinson M. Effects of positive and negative emotions on salivary IgA. *J Adv Med.* 1995;8(2):87-105.
33. Koepchen HP. History of studies and concepts of blood pressure waves. In: Miyakawa K. *Mechanisms of Blood Pressure Waves.* Tokyo. Japan: Springer-Verlag; 1984:3-23.
34. Akselrod S. Gordon D. Madwed JB. Snidman NC. Shannon DC. Cohen RJ. Hemodynamic regulation investigation by spectral analysis. *Am J Physiol.* 1985:249 (suppl):H867-H875.
35. Langhorst P. Schulz G. Lambertz M. Integrative control mechanisms for cardiorespiratory and somatomotor functions in the reticular formation of the lower brain stem. in: Grossman P. Janssen KHL. Vaitl D. *Cardiorespiratory and Cardiosomatic Psychophysiology.* New York. NY: Plenum Press. 1983: 9-39.
36. Raschke F. Coordination in the circulatory and respiratory systems. In: Rensing L. Heiden U. Mackey MC. *Temporal Disorder in Human Oscillatory Systems.* Berlin. Germany: Springer-Verlag; 1986: 152-158.
37. McCraty R. Atkinson M. Tiller WA. New electrophysiological correlates associated with intentional heart focus. *Subtle Energies.* 1995:4:251-268.
38. Cowan MJ. Kogan H. Burr R. Hendershot S. Buchanan L. Power spectral analysis of heart rate variability after biofeedback training. *J Electrocardiol.* 1988;23(suppl):85-93.
39. Kitney RI. Heart rate variability in normal adults. In: Grossman P, Janssen KHL. Vaitl D. *Cardiorespiratory and Cardiosomatic Psychophysiology.* New York. NY: Plenum Press; 1983:83-99.
40. Paddison S. *The Hidden Power of the Heart.* Boulder Creek. Calif: Planetary Publications; 1992:280.
41. Wester M. AcqKnowledge. Goleta. Calif: BIOPACK Systems. Inc; 1993.
42. DADiSP/32. 1993. Cambridge. Mass: DSP Development Corp.
43. Taylor I. Duthie HL. Smallwood R. Brown BH. Linkens DA. The effects of stimulation on the myoelectrical activity of the rectosigmoid in man. *Gut.* 1974;15:599-607.
44. Rozman D. Whitaker R. Beckman T. Jones D. A new intervention program which significantly reduces psychological symptomatology in HIV-seropositive individuals. *Psychosomatics.* 1994:36:207-208.
45. Stern RM. Anschel C. Deep inspirations as stimuli for responses of the autonomic nervous system. *Psychophysiol.* 1968:5-132.
46. DeBenedittis G. Cigada M. Bianchi A. Signorini MG. Cerutti S. Autonomic changes during hypnosis: a heart rate variability power spectrum analysis as a marker of sympatho-vagal balance. *Int J Clin Exp Hypnosis.* 1994:XLII(2):140-152.
47. Hatch JP. Borcherding S. Norris LK. Cardiopulmonary adjustments during operant heart rate control. *Psychophysiology.* 1990:27:641-647.
48. Aguirre A. Wodicka GR. Maayan C. Shannon DC. Interaction between respiratory and RR interval oscillations at low frequencies. *J Auton Nerv Syst.* 1990;29:241-246.
49. Robbe HWJ. Mulder LJM. Ruddel H. Langewitz WA. Veldman JBP. Mulder G. Assessment of baroreceptor reflex sensitivity by means of spectral analysis. *Hypertension.* 1987:10:538-543.
50. Sanders JS. Mark AL. Ferguson DW. Importance of baroreflex in regulation of sympathetic responses during hypotension: evidence from direct sympathetic nerve recordings in humans. *Circulation.* 1989:79:83-92.
51. Eckberg DL. Rea RF. Anderson KO. et al. Baroreflex modulation of sympathetic activity and sympathetic neurotransmitters in humans. *Acta Physiol Scand.* 1988:133:221-231.
52. Ebert TJ. Morgan BJ. Barney JA. Denahan T. Smith JJ. Effects of aging on baroreflex regulation of sympathetic activity in humans. *Am J Physiol.* 1992;263 (suppl):H798-H803.
53. DeBoer RW. Karemaker JM. Strackee J. Hemodynamic fluctuations and baroreflex sensitivity in humans: a beat-to-beat model. *Am J Physiol.* 1987;253(suppl):680-689.
54. Brooks D. Fox P. Lopez R. Sleight P. The effect of mental arithmetic on blood pressure variability and baroreflex sensitivity in man. *Proc Physiol Soc.* 1978;280:75-76.
55. Bristow JD. Honor AJ. Pickering TG. Sleight P. Cardiovascular and respiratory changes during sleep in normal and hypertensive subjects. *Cardiovasc Res.* 1969;3:476-485.
56. Bertinieri G. Rienzo M. Cavallazzi A. et al. Baroreceptor-heart rate reflex studied in normotensive and essential hypertensives by beat-to-beat analysis of 24-hour blood pressure and heart rate. *J Hypertens.* 1987;5(suppl 5):5333-5335.
57. Gribbin B. Pickering TG. Sleight P. Peto R. Effect of age and high blood pressure on baroreflex sensitivity in man. *Circ Res.* 1971:29:424-431.
58. Wiesenfeld K. Moss F. Stochastic resonance and the benefits of noise: from ice ages to crayfish and squids. *Nature.* 1995;373;33-36.
59. Poponin V. Nonlinear stochastic resonance in weak EMF interactions with diamagnetic ions bound within proteins. In: Allen MJ. Cleary SF. Sower AE. *Charge and Field Effects in Biosystems.* River Edge. NJ: World Scientific; 1994:306-319.
60. Walleczek J. Field effects on cells of the immune system: the role of calcium signaling. *Fed Am Soc Exp Biol.* 1992;6:3177-3185.
61. Litovitz TA. Krause D. Mullins JM. Effect of coherence time of the applied magnetic field on ornithine decarboxylase activity. *Biochem Biophys Res Commun.* 1991;178:262-265.
62. Polosa C. Rhythms in the activity of the autonomic nervous system: their role in the generation of systemic arterial pressure waves. In: Miyakawa K. *Mechanisms of Blood Pressure Waves.* Tokyo. Japan: Springer-Verlag (Berlin); 1984:27-41.
63. Koizumi K. Terui N. Kollai M. Relationships between vagal and sympathetic activities in rhythmic fluctuations. In: Miyakawa K. *Mechanisms of Blood Pressure Waves.* Tokyo. Japan: Springer-Verlag (Berlin); 1984:43-56.
64. Pollak MH. Obrist PA. Aortic-radial pulse transit time and ECG Q-wave to radial pulse wave interval as indices of beat-by-beat blood pressure change. *Psychophysiology.* 1983:20(1):21-28.
65. Barry RJ. Mitchell FH. A comparison of phasic cardiac responses derived from the electrocardiogram and the peripheral pulse. *Int J Psychophysiol.* 1987;5:73-78.