ELECTROPHYSIOLOGICAL CORRELATES OF POSITIVE EMOTIONS: THREE PATTERNS OF SYMPATHOVAGAL BALANCE IN NORMAL SUBJECTS

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ABSTRACT

Power spectral density (PSD) analysis of heart rate variability has been used to investigate autonomic tone during stress, but little is known about its regulation during emotional states. We studied the PSD of 20 subjects, trained in a mental and emotional self-management technique called Freeze-Frame, under controlled laboratory conditions and at work under real-life stressful situations. Power spectral density plots were divided into three regions: low frequency, LF (0.01-0.05 Hz), which is predominantly sympathetic activity, mid-frequency, MF (0.05-0.15 Hz), and high frequency, HF (0.15-0.5 Hz), which is predominantly parasympathetic activity. Three patterns of autonomic activity could be clearly discriminated in the HRV tachograms and the PSD plots, namely the normal resting mode, an entrainment mode, and a pattern new to the electrophysiology literature which we have called internal coherence. Each of these electrophysiological states are characterized by different emotional experiences. We provide evidence for the entrainment and internal coherence modes in a group of 20 subjects who were able to enter and maintain these modes at will using the Freeze-Frame technique. We also demonstrated that, when an individual is in the entrainment mode, other physiological systems frequency-lock to the entrainment frequency(~0.1 Hz). These results suggest that emotional experiences play a role in determining sympathovagal balance independent of heart rate and respiration. Furthermore, these data suggest that a positive emotional focus may promote a more cardioprotective autonomic profile, which may help reduce the likelihood of sudden death in patients with congestive heart failure and coronary artery disease and may be of benefit in the treatment of hypertension.

Key Words: Electrocardiogram, heart rate variability, autonomic nervous system, entrainment, internal coherence, power spectrum, electrophysiology, emotion

INTRODUCTION

Heart rate variability (HRV), as measured by the beat-to-beat variation in R-R intervals derived from the electrocardiogram (ECG), has been shown to be an important physiological parameter [1-5]. In addition, the mathematical transformation of HRV into power spectral density (PSD) is commonly used as a non-invasive test of integrated neurocardiac function, since it can distinguish sympathetic from parasympathetic regulation of the heart rate [6]. Over the last few years there has been an explosion in the number of studies using HRV and PSD analysis to investigate the role of the autonomic nervous system in normal and pathological states particularly heart disease. For example, HRV analysis has been shown to be an independent risk factor for death in patients with chronic heart failure [7], post cardiac catheterization [8] and post myocardial infarction [9]. These findings can be partly explained by the shift in sympathovagal balance that occurs in most cardiovascular disease. Thus, decreased parasympathetic tone has been reported following acute myocardial infarction [10], hypertension [6],and heart failure [11], and increased sympathetic tone has been shown to lower the threshold for ventricular fibrillation [12].

The reason for this shift in sympathovagal balance in cardiovascular disease, with increased sympathetic and decreased parasympathetic tone, has, until recently, remained obscure. However, there is now substantial evidence to suggest that mental and emotional stress increases sympathetic and reduces parasympathetic activity [13-15]. This may explain why mental and emotional stress can predict the risk of cardiac death following acute myocardial infarction [16], and may predict the development of hypertension [17, 18]. Thus, programs aimed at decreas-

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ing emotional distress can significantly reduce the long term risk of cardiac mortality [19, 20]. Such programs may be effective because of their tendency to promote less cardiotoxic autonomic activity, reducing sympathetic arousal and increasing parasympathetic activity through reducing emotional reactivity and anger and promoting emotional balance. We have recently demonstrated that individuals can be specifically taught to develop a more cardioprotective pattern of autonomic activity, using a number of self-management techniques which alter sympathovagal balance[21].

The present study extends our previous work and describes three different patterns of autonomic activity that can be seen at rest and following the use of these self-management techniques. These patterns are: the normal resting mode, the entrainment mode and a new electrophysiological mode we have called internal coherence. We have demonstrated that these patterns of autonomic activity not only occur in the lab under controlled conditions, but can also be seen in the work place during real-life stressful events. The physiological and clinical implications of these electrophysiological patterns of autonomic order are discussed.

METHODS

We assessed the HRV and PSD of 20 normal healthy individuals during a 10-minute baseline period followed by a 5-minute period of emotional expression under controlled conditions in the lab. To facilitate the shift from a resting baseline state to a state of positive emotional expression, all subjects were trained in a self-management technique called Freeze-Frame (FF). In addition, using ambulatory ECG monitoring, we studied the HRV and PSD of all subjects during real-life stressful situations and following the use of the FF technique to manage their stress.

We recruited twenty men and women for this study: 10 females and 10 males, aged 24-47 (mean = 39) years. All subjects were in good general health with no history of cardiovascular disease and were not currently taking prescription drugs known to affect cardiovascular function. Subjects were instructed to abstain from alcohol, caffeine and nicotine for 4 hours prior to the laboratory session.

Inducing a Positive Emotional State

The subjects used the FF technique, as previously described [21-23]. Briefly, this technique trains subjects to consciously disengage from mental and emotional reactions by shifting attention to the heart, which most people associate with positive emotions. Subjects are then taught to focus on "sincerely feeling" appreciation, or a similar positive emotion, toward someone or something, in contrast to "positive thinking" which involves mentally recalling or visualizing a past experience.

Procedures

In the laboratory arm of the study, the subjects were seated in straight, high backed chairs to minimize postural changes and fitted with disposable Ag/AgCl ECG electrodes. The positive electrode was located on the left side at the 6th rib and the reference was placed in the right supraclavicular fossa. Grass model 7P4 amplifiers were used in this study. Respiration was monitored with a Resp-EZ piezoelectric belt around the chest. The pulse transit time (PTT), which is the time interval between the peak of the R-wave and the appearance of the pulse wave associated with that same cardiac contraction at the index finger on the left hand, was recorded using a Grass model 80 cardiac microphone.

All measurements were recorded throughout the entire 10 minute baseline period, with the last 5 minutes of data used for analysis. Subjects were then asked to use the FF technique to facilitate a shift to a positive emotional state, which they then maintained for the subsequent 5 minutes. Five minutes is the minimum time required to accurately resolve frequencies down to 0.01 Hz in the HRV power spectrum and the maximum time that some subjects could sustain the emotional focus. Heart rate, short term HRV and PSD measures were calculated from these two 5-minute periods. Five subjects were studied per session. A total of 4 sessions were conducted at the same time of day (10 AM) over a one week period. After informed consent was obtained, and prior to each session, subjects were asked to refrain from talking, falling asleep, making exaggerated body movements or intentionally altering their respiration. Subjects were carefully monitored to ensure there were no significant respiratory or postural changes during the session.

In the work environment arm of the study, 24-hour ambulatory ECG recording was accomplished by fitting the same 20 subjects with three-channel Holter recorders (DelMar model 363). This 24-hour period included a normal business day at the subjects' place of work. Subjects were asked to use the FF technique on at least 3 separate occasions when they felt under stress. They were instructed to press the Holter recorder event marker each time they used the FF technique. The period of positive emotional expression was, of course, not preceded by a 10-minute resting baseline period, nor was it possible to control for postural changes.

HRV Analysis

The short term HRV signal is in the form of an R-R interval tachogram. PSD was obtained from the analysis of successive discrete R-R interval series taken from the ECG signal, sampled at 256 Hz. All data was digitized by a Bio Pac 16 bit digitizer and software system. Analyses of HRV, Fast Fourier Transforms (FFT), PSD (calculated as $(BPM)^2/Hz$) and time domain measurements were made using DADiSP/32 digital signal processing software.

We divided the power spectrum into three major frequency ranges (LF, MF and HF), as previously described [4, 24, 25]. The integral of the power spectrum within each region was then calculated. The LF region (0.01 to 0.05 Hz) is primarily considered a measure of sympathetic activity with a minor parasympathetic component [4]. In contrast, the HF region (0.15 to 0.5 Hz) is associated with respiratory sinus arrhythmia and is almost exclusively due to parasympathetic activity [3, 4, 25]. The LF/HF ratio has been used as a measure of sympathovagal balance [2, 14, 26] and the MF region (0.05 to 0.15 Hz) has been used as an indirect indicator of activity in the baroreceptor feedback loop controlling blood pressure [27]. Power in the MF region is thought to be mixed sympathetic and parasympathetic activity, but predominately the latter [4]. In addition, total autonomic power (LF + MF + HF) and the MF/(LF + HF) ratio were calculated.

Statistical Analysis

The raw data baseline values were compared to the during Freeze-Frame values and were analyzed for statistical significance using the Wilcoxon Signed Ranks Test utilizing the sum of the ranks for positive and negative differences for each group where Z= (sum of signed ranks) /Square root (sum of squared ranks).

Results

Laboratory Arm of the Study

1. Normal resting pattern of HRV.

Representative HRV traces of the three patterns of autonomic nervous system order are presented in Figure 1. The left-hand panels are HRV tachograms showing the beat-to-beat changes in heart rate in the time domain. The middle panels in Figure 1 show the power spectral density (PSD) plots of the HRV waveforms. The PSD gives an estimate of the energy within each different frequency band. The right-hand panels show the Fast Fourier transforms (FFT) of a single 10-second epoch of the raw ECG data from which the HRV and PSD plots were derived. These plots illustrate the frequency of the electromagnetic energy produced by a 10-second series of heart beats and helps to clarify the relationship between HRV and the frequency of the electromagnetic energy produced by the heart.

Three different patterns of autonomic activity, related to differing emotional states, could be clearly discriminated during the laboratory arm of the study. While subjects were sitting quietly, the HRV tachogram showed a variable degree of irregularity, with the heart rate ranging from 58 bpm to 82 bpm. The more disordered pattern shown in Figure 1A commonly occurs during periods of frustration and anger, and can be induced by simply having the subjects recall an event that makes them feel angry [21]. PSD analysis of the HRV data demonstrated that the power was typically scattered across all three frequency bands (Figure 1B) and the Fast Fourier transforms of the ECG data revealed a chaotic signal with numerous frequencies scattered throughout the spectrum (Figure 1C).

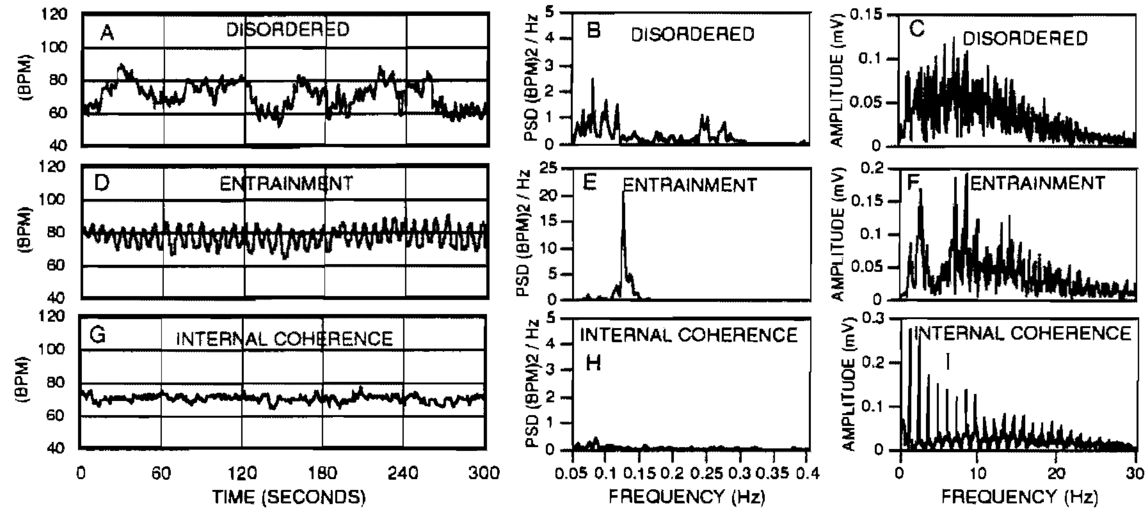

Figure 1. A, D and G Heart rate tachograms: A illustrates a disordered pattern of HRV that occurs when subjects are feeling frustrated. D illustrates a sinusoidal pattern of HRV that occurs when subjects are feeling sincere appreciation. G illustrates the reduction of HRV amplitude that is accompanied by an inner feeling state we call amplified peace. Figure 1B, E and H represent power spectral density plots of the corresponding HRV tachograms shown in Figure 1A, 1D and 1G respectively. Figure 1C, F and I represent FFTs of a 10 sec. epoch of ECG data from which the HRV tachograms shown in 1A, 1D and 1G were derived.

2. Entrainment Mode.

When the subjects used the FF technique to generate a state of positive emotional expression, significant changes in the HRV, PSD and FFT data were produced. In the majority of subjects the HRV tachograms changed to a sine wave-like signal (Figure 1D). The PSD analysis of this data showed the development of a very narrow, high amplitude signal in the MF (0.1Hz) region of the HRV power spectrum, with few or no other peaks in the LF and HF regions (Figure 1E). The shift in autonomic activity which produces a large MF peak in the HRV power spectrum indicates that respiration and pulse transit time have frequency-locked with the HRV rhythm. This frequency locking has been previously described and is referred to as "entrainment" [28, 29]. An example of frequency locking between HRV, PTT and respiration is presented in Figure 2A, and the PSD analysis of this data before and after the FF is presented in Figures 2B and 2C respectively. By using the FF technique, subjects could enter the entrainment mode at will by sincerely experiencing a positive emotional state such as appreciation, care or love.

FFT analysis of the ECG data revealed a reduced degree of "interference" between the different frequency peaks, with fewer intermediate frequencies between the main peaks (Figure 1F).

3. Internal coherence mode.

Four of the subjects in the laboratory arm of the study produced a third pattern of autonomic order, new to the electrophysiological literature, which is represented in Figures 1G to 1I and Figure 3. In this mode, which we have called internal coherence, the variability in the heart rate tachogram was dramatically reduced (Figure 1G). The PSD plot of this data showed that a substantial reduction in total autonomic power across all frequency bands had occurred (Figure 1H). The equivalent ECG frequency plot of the same data revealed a much greater reduction in the "interference" between the different frequency bands than is seen in the entrainment mode, producing the equivalent of a "clean" harmonic spectrum of standing waves (Figure 1I). Thus, the mode of internal coherence could be defined, in electrophysiological terms, as that mode which produces a reduction in PSD across all frequency bands in the HRV spectrum and produces at least seven harmonics in the Fast Fourier Transform of the ECG data, with few intermediate frequencies having a significant amplitude.

Figure 3A illustrates a subject consciously making a transition from the entrainment mode to the internal coherence mode, in real time, while Figure 3B shows the change in PSD analysis as a result of this shift.

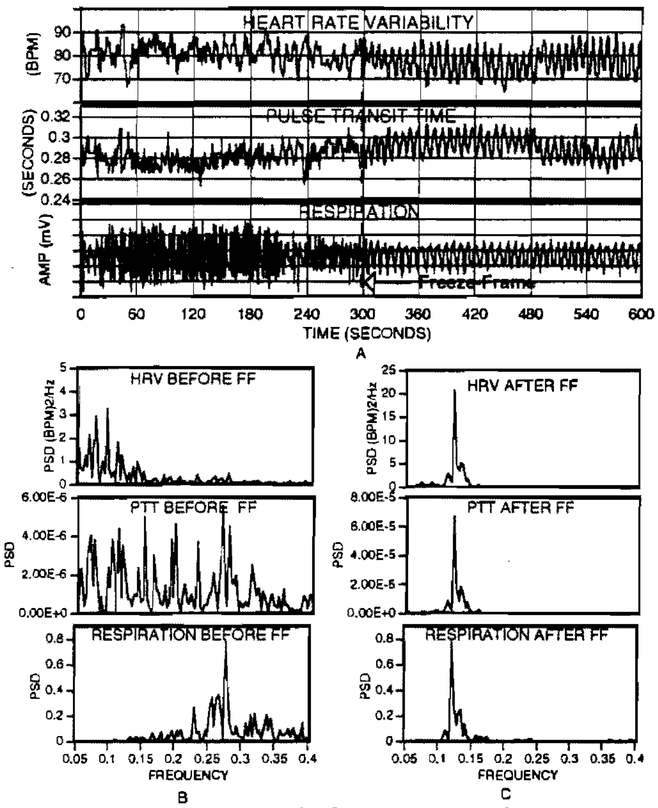

Figure 2A. HRV, PTT and respiration before and during a "Freeze-Frame"(FF) commencing at around 300 sec. Figure 2B is the PSD analysis of HRV, PTT and respiration, before Freeze-Frame. Figure 2C is the PSD analysis of HRV, PTT and respiration, after Freeze-Frame.

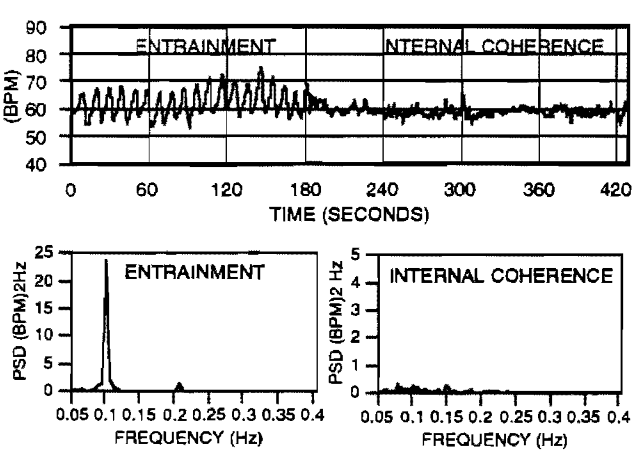

Figure 3. Illustration of a subject's intentional shifting from the entrainment mode to the internal coherence mode.

Analysis of the data obtained from the laboratory arm of the study revealed that, of the 20 subjects, 16 entered the entrainment mode with a main PSD peak occurring at approximately 0.1Hz, and four subjects entered the internal coherence mode, with significant reductions in total autonomic power across all frequencies. Table 1 presents the PSD values for the entire group and Tables 2 and 3 for each subgroup during the baseline and FF periods plus the mean heart rate, and heart rate standard deviation. There was no significant difference in heart rate between the baseline period and during FF for either the entrainment or internal coherence subgroup. In contrast, heart rate standard deviation showed opposite trends in the two subgroups, increasing significantly during FF in the entrainment group (P = .005) and decreasing during FF in the internal coherence group.

Analysis of the mean spectral data for the entrainment subgroup revealed that, during the FF period, there was a significant increase in MF ($p < .001$) and HF power ($p < 0.01$) and a more than two-fold increase in total autonomic power ($p < 0.001$). There was also a significant increase in the MF/(LF+HF) ratio ($p < 0.01$). In contrast, the internal coherence subgroup demonstrated a decrease in the MF power and a decrease in the MF/(LF+HF) ratio. There was also a decrease in the LF and total autonomic power in the internal coherence subgroup, although statistics could not be performed due to the small number of subjects in this sub group.

Table 1. Cardiovascular characteristics of the group analyzed as a whole from the In-lab-study. Values represent raw data ± standard deviation before and during the Freeze-Frame (n=20).

	Baseline	(SD)	During FF	(SD)	Z	p
LF	0.057	(.04)	0.034	(.02)	1.72	NS
MF	0.07	(.03)	0.218	(.23)	2.91	.004
HF	0.025	(.01)	0.039	(.02)	2.95	.003
Total Power	0.152	(.07)	0.29	(.25)	2.35	.019
LF/HF	2.905	(2.23)	1.669	(3.40)	2.73	.006
MF/(LF+HF)	0.98	(.48)	2.818	(2.30)	3.25	.001
HR	81.495	(11.28)	80.313	(10.85)	1.57	NS
HRSD	5.213	(1.13)	6.267	(2.58)	1.83	NS

Table 2. Cardiovascular characteristics for the entrainment subgroup from the In-lab-study. Values represent raw data ± standard deviation before and after the Freeze-Frame (n=16).

	Baseline	(SD)	During FF	(SD)	Z	p
LF	0.053	(.03)	0.039	(.02)	1.034	NS
MF	0.071	(.04)	0.269	(.23)	3.516	<.001
HF	0.026	(.01)	0.039	(.02)	2.585	<.01
Total Power	0.149	(.07)	0.347	(.25)	3.309	<.001
LF/HF	2.748	(2.26)	1.937	(3.77)	2.224	0.026
MF/(LF+HF)	1.036	(.51)	3.456	(2.12)	3.516	<.001
HR	80.812	(7.94)	80.038	(7.90)	0.983	NS
HRSD	5.183	(1.05)	7.001	(2.29)	2.644	0.005

Table 3. Cardiovascular characteristics for the Internal Coherence subgroup from the In-lab-study. Values represent raw data ± standard deviation before and after the Freeze-Frame (n=4).

	Baseline	(SD)	During FF	(SD)
LF	0.077	(.05)	0.016	(.01)
MF	0.066	(.03)	0.011	(.00)
HF	0.022	(.01)	0.035	(.03)
Total Power	0.166	(.08)	0.062	(.03)
LF/HF	3.532	(2.31)	0.596	(.56)
MF/(LF+HF)	0.754	(.23)	0.265	(.15)
HR	84.227	(21.86)	81.412	(20.78)
HRSD	5.33	(1.60)	3.333	(.83)

Workplace Arm of the Study

A total of 51 FF responses from the Holter tape data were identified as artifact-free and suitable for analysis. Table 4 shows the results of the data when analyzed as a whole and Tables 5 (entrainment) and 6 (other) show the data when analyzed as sub groups. Analysis of the entire group reveled a significant decrease in LF power ($p < .0001$) the LF/HF ratio ($p < .0001$) and HRSD ($p = .03$). There were significant increases in MF power ($p = .02$), HF power ($p < .0001$), the MF/(LF+HF) ratio ($p < .001$) and heart rate ($p < .0001$).

The data was then divided into two an entrainment sub group and a sub group containing all other FF's classified as internal coherence or other similar types of patterns. The entrainment sub group showed a significant decrease in LF power ($p = .0129$), and the LF/HF ratio ($p = .002$). There were significant increases in MF power ($p = .0001$), HF power ($p = .0096$), the MF/(LF+HF) ratio ($p = .0001$), total power ($p = .0078$) and heart rate ($p = .0012$).

The non-entrainment or other sub group showed a significant decrease in LF power ($p < .0001$), total power ($p = .0316$) the LF/HF ratio ($p < .0001$) and HRSD ($p = .0001$). There was a significant increase in HF power ($p = .001$) and heart rate ($p < .0001$).

Table 4. Cardiovascular characteristics for the out-of-lab study when analyzed a whole group. Values represent raw data ± standard deviation before and after the Freeze-Frame. (n=51)

	Baseline	(SD)	During FF	(SD)	Z	p
LF	0.258	(.30)	0.107	(.08)	4.71	<.0001
MF	0.201	(.18)	0.358	(.40)	2.31	.02
HF	0.064	(.07)	0.131	(.15)	4.10	<.0001
Total Power	0.553	(.48)	0.564	(.54)	.54	NS
LF/HF	6.895	(8.33)	1.304	(1.04)	5.88	<.0001
MF/(LF+HF)	0.721	(.43)	1.649	(1.98)	3.67	<.001
HR	97.35	(12.81)	111.44	(15.80)	5.50	<.0001
HRSD	7.97	(3.49)	7.1	(3.54)	2.17	.03

Table 5. Cardiovascular characteristics for the out-of-lab study entrainment sub group. Values represent raw data ± standard deviation before and after the Freeze-Frame. (n=21)

	Baseline	(SD)	During FF	(SD)	Z	p
LF	.288	(.24)	.143	(.10)	2.49	.0129
MF	.254	(.17)	.658	(.41)	3.81	.0001
HF	.073	(.07)	.148	(.13)	2.59	.0096
Total Power	.815	(.42)	.948	(.55)	2.66	.0078
LF/HF	6.883	(5.94)	1.632	(1.28)	3.67	.0002
MF/(LF+HF)	.817	(.34)	2.839	(2.39)	3.98	.0001
HR	99.258	(12.51)	111.088	(14.01)	3.25	.0012
HRSD	8.298	(3.54)	9.451	(3.32)	1.51	NS

Table 6. Cardiovascular characteristics for the out-of-lab study internal coherence and non-entrainment sub group. Values represent raw data ± standard deviation before and after the Freeze-Frame. (n=30)

	Baseline	(SD)	During FF	(SD)	Z	p
LF	.268	(.33)	.082	(.08)	4.14	<.0001
MF	.165	(.15)	.145	(.21)	1.72	NS
HF	.056	(.08)	.120	(.18)	3.30	.0010
Total Power	.511	(.48)	.347	(.38)	2.15	.0316
LF/HF	6.917	(8.89)	1.075	(.80)	4.58	<.0001
MF/(LF+HF)	.853	(.48)	.816	(.98)	.32	NS
HR	96.012	(13.05)	111.692	(17.17)	4.43	<.0001
HRSD	7.751	(3.49)	5.452	(2.67)	3.96	.0001

DISCUSSION

The management of mental and emotional dysfunction traditionally involves a variety of psychotherapeutic interventions and more psychological approaches like cognitive restructuring and neurolinguistic programming. In addition, a number of alternative techniques, which involve attentional shifts, have been employed. For example, Yoga attempts to "still the mind" by focusing attention on the breath or differing parts of the brain, whereas Qigong focuses on the "Dan Tien" point (just below the navel). In contrast, the FF technique used in this study focuses attention on the area around the heart. All of these techniques shift attention to areas of the body which possess intrinsic automaticity, *i.e.* pacemaker cells within these areas spontaneously generate a rhythmic electrical output. These areas of the body, that possess intrinsic automaticity, are referred to as "biological oscillators" [30]. By using paced breathing, meditation or yoga and intentionally focusing attention on respiration it is possible to alter the intrinsic oscillatory rhythm of the respiratory center in the brain [31]. It is feasible that the frequency and rhythms of the intestinal peristaltic contractions, which are normally in the same frequency range as the HRV rhythm [32], may be similarly modified by focusing attention in the area of the gut. The effectiveness of hypnosis in irritable bowel disease may, in part, be due to an alteration of the intrinsic rhythm of intestinal contractions brought about by the increase in parasympathetic nervous system activity that occurs in the hypnotic state [33]. In this study we have shown that shifting attention to the area around the heart, and experiencing a positive emotional state, produces a significant shift in cardiac rhythm. This shift in cardiac rhythm produces a sinusoidal HRV trace with the heart rate rising and falling regularly every ten seconds (0.1Hz), in addition to a shift in autonomic activity with increased power in the mid and high frequency end of the HRV power spectra.

It is well known that mechanical systems entrain to the frequency and rhythm generated by the most powerful signal [34, 35]. This study, along with previous work from our laboratory [36], suggests that entrainment also occurs in biological oscillators, such as vascular smooth muscle, respiratory centers and other centers in the brain. Since the heart generates the most powerful electromagnetic and hemodynamic rhythms in the body, it follows that the other biological oscillators will entrain to the rhythms generated by the cardiac pacemakers.

The clinical implications of entrainment of the biological oscillators at 0.1 Hz are not yet fully understood. However, we have previously demonstrated that the shift in sympathovagal balance that follows use of the FF technique, and the consequent increase in power at the 0.1Hz frequency [21], produces a significant increase in salivary IgA [22, 37] and may protect against death from ischaemic heart disease [21]. While conscious control of respiration [28], neutral hypnosis [33] and operant conditioning of heart rate [38] have also been shown to produce shifts in sympathovagal balance, their effects on PSD analysis and immunological function are unclear.

Similarly, the clinical implications of internal coherence are unknown. Generally HRV decreases with age [2], and a decline in HRV amplitude or total autonomic power is considered to be both detrimental and a poor prognostic indicator in ischaemic heart disease [39]. However, we suggest that this generalization may not hold true in normal healthy individuals where the reduction in total autonomic power, seen when individuals enter the internal coherence mode, may merely indicate that the sympathetic and parasympathetic outflow from the brain to the heart is reduced to such a degree that the oscillations in the HRV are greatly reduced. This ability of healthy individuals to reduce their HRV to near zero indicates, we suggest, a great degree of mental and emotional self-management and flexibility. This is in contrast to the pathological loss of HRV, seen in ischaemic heart disease, which indicates a loss of flexibility with the sinoatrial node unable to respond to autonomic innervation. The state of internal coherence may partly explain why some otherwise healthy individuals have a very low HRV [2], a fact which has hitherto limited the clinical utility of HRV analysis for unequivocally predicting the development of cardiovascular disease[2].

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[40, 41]. Further evidence suggests that coherent electromagnetic fields may have important implications for cellular function. For example, it has been recently demonstrated that nonthermal extremely low frequency electromagnetic signals may affect intracellular calcium signaling [42]. In addition, coherent electromagnetic fields have been shown to produce substantially greater cellular effects on enzymatic pathways, such as Ornithine Decarboxylase activity, than incoherent signals [43]. This suggests that the state of internal coherence may also affect cellular function and provides a potential link between autonomic function, HRV and cellular processes.

Both the entrainment and internal coherence modes are characterized by different emotional experiences and these electrophysiological modes change as the emotional state changes. Entrainment is typically produced by experiencing the feelings of sincere appreciation or love, while individuals entering a state leading to internal coherence describe a feeling of deep connectedness, profound peace and minimal mental and emotional dialog. Both states can be consciously produced and, although the duration that a subject can hold these states is brief at first, with practice they can be maintained for increasingly longer periods of time. Subjects also frequently reported heightened intuitive awareness in both states, and anecdotal evidence suggests that significant reductions in blood pressure may occur in hypertensive patients during and after they enter the entrainment mode (unpublished observations).

Recent evidence suggests that there may be a reciprocal relationship between baroreceptor activity and sympathetic drive, with increased baroreceptor activity inhibiting sympathetic outflow [44-46], while stress increases sympathetic drive and inhibits baroreflex activity [47]. Baroreceptor activity is known to be sensitive to various psychological states [48], and we believe that the increase in MF power that occurs during the positive emotional experience of FF represents an increase in baroreceptor afferent activity. Therefore, FF may reduce the sensation of stress by increasing baroreceptor activity and inhibiting sympathetic outflow from the brain. In addition, the increase in MF power that is seen during entrainment may have important implications for the control of hypertension, since baroreflex sensitivity is reduced in these individuals [49, 50].

Data from the workplace arm of the study suggests that the FF technique is equally effective at producing the electrophysiological changes seen in the laboratory under real life stressful situations. Anecdotal reports suggest that most subjects found the FF technique effective in reducing their levels of stress in the workplace.

In conclusion, this study demonstrates that shifting attention to the area around the heart combined with a positive emotional focus can produce a shift in sympathovagal balance with a resultant change in the electrical frequencies generated by the heart. This shift leads to entrainment of other biological oscillators in the body. Although we only examined a small number of subjects over a short period of time, these results support previous studies and suggest that positive emotional states which promote synchronicity in biological systems may have important implications for immunity, cardiovascular function and the perception of stress. The characterization of a new electrophysiological mode, called internal coherence, demonstrates the ability of subjects to significantly reduce mental and emotional processing and autonomic activity. Larger studies, with a greater number of subjects and longer assessment of HRV, are now required to determine whether the potential of this type of behavioral intervention can be broadly realized.

References

1. Kleiger RE, Stein PK, Bosner MS and Rottman JN. (1992) Time domain measurements of heart rate variability. *Amb. Electrocardio.*, 10(3): 487-498.
2. Ori Z, Monir G, Weiss J, Sayhouni X and Singer DH. (1992) Heart rate variability frequency domain analysis. *Amb. Electrocardio.*, 10(3): 499-537.
3. Pomeranz B, Macaulay JB and Caudill MA. (1985) Assessment of autonomic function in humans by heart rate spectral analysis. *Am. J. Physiol.*, 248: H151-H158.
4. Akselrod S, Gordon D, Ubel FA, Shannon DC, Barger AC and Conen RJ. (1981) Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. *Science*, 213(10): 220-222.
5. Appel ML, Berger RD, Saul P, Smith J and Cohen R. (1989) Beat to beat variability in cardiovascular variables: noise or music? *J.A.C.C.*, 14(5): 1139-1148.
6. Pagani M, Lombardi F and Guzzette S. (1986) Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Cir. Res.*, 59: 178-184.
7. Frey B, Binder T, Teufelsbauer H, Wutte M, Kreiner G, Gossinger H, Schmidinger H, Pacher R and Weber H. (1993) Heart rate variability and patient outcome in advanced heart failure. *Am. J. Cardiol.*, 21: 286A.
8. Saini MW, Kleiger RE, Carney RM, teVelde A and Freedland KE. (1988) Correlation of heart rate variability with clinical and angiographic variables and late mortality after coronary angiography. *Am. J. Cardiol.*, 62: 714-717.
9. Kleiger RE and Miller JP. (1978) Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. *Am. J. Cardiol.*, 59: 256-262.
10. Rothschild M, Rothschild A and Pfeifer M. (1988) Temporary decrease in cardiac parasympathetic tone after acute myocardial infarction. *Am. J. Cardiol.*, 62: 637.
11. Saul JP, Arai Y, Berger RD, Lilly LS, Colucci WS and Cohen RJ. (1988) Assessment of autonomic regulation in chronic congestive heart failure by heart rate spectral analysis. *Am. J. Cardiol.*, 61: 1292-1299.
12. Lown B, DeSilva M and Lenson R. (1978) Role of psychologic stress and autonomic nervous system changes in provocation of ventricular premature complexes. *Am. J. Cardiol.*, : 979-985.
13. Lindqvist A, Keskinen E, Antila K, Halkola L, Peltonen T and Välimäki I. (1983) Heart rate variability, cardiac mechanics, and subjectively evaluated stress during simulator flight. *Aviation, Space and Environmental Medicine*, (August): 685-690.
14. Kamada T, Miyake S, Kumashiro M, Monou H and Inoue K. (1992) Power spectral analysis of heart rate variability in type As and type Bs during mental workload. *Psychosom. Med.*, 54: 462-470.
15. Kollai M and Kollai B. (1992) Cardiac vagal tone in generalised anxiety disorder. *British Journal of Psychiatry*, 161: 831-835.
16. Shelelle RB, Vernon SW and Ostfeld AM. (1991) Personality and coronary heart disease. *Psychosom. Med.*, 53: 176-184.
17. Markovitz JH, Matthews KA, Kannel WB and Cobb JL. (1993) Psychological predictors of hypertension in the Framingham study: is there tension in hypertension? *Journal of the American Medical Association*, 270(20): 2439-2494.
18. Conway J, Boon N, Jones JV and Sleight P. (1983) Involvement of the baroreceptor reflex in changes in blood pressure with sleep and mental arousal. *Hyperten.*, 5: 746-748.

19. Frasure-Smith N. (1991) In-hospital symptoms of psychological stress as predictors of long-term outcome after acute myocardial infarction in men. *Am. J. Cardiol.*, 67: 121-127.
20. Dracup K, Moser DK, Marsden C, Taylor SE and Guzy PM. (1991) Effects of a multidimensional cardiopulmonary rehabilitation program on psychosocial function. *Am. J. Cardiol.*, 68: 31-34.
21. McCraty R, Atkinson M, Tiller WA, Rein G and Watkins A. (1995) The effects of emotions on short term power spectrum analysis of heart rate variability. *Am. J. Cardiol.*, In press, 1995.
22. Rein G and McCraty RM. (1995) Effects of positive and negative emotions on salivary IgA. *J. Adv. of Med.*, 8(2): 87-105.
23. Childre DL. (1994) Freeze Frame®, fast action stress relief, Boulder Creek, Planetary Publications, 132.
24. Yeragani VK, Pohl R, Berger R, Balon R, Ramesh C, Glitz D, Srinivasan K and Weinberg P. (1993) Decreased HRV in panic disorder patients: a study of power-spectral analysis of heart rate. *Psychiat. Res.*, 46: 89-13.
25. Akselrod S, Gordon D, Madwed JB, Snidman NC, Shannon DC and Cohen RJ. (1985) Hemodynamic regulation investigation by spectral analysis. *Am. J. Physiol.*, 249 (Heart Circ. Physiol. 18): H867-H875.
26. Sloan RP, Shapiro PA, Bigger JT, Bagiella E, Steinman RC and Gorman JM. (1994) Cardiac autonomic control and hostility in healthy subjects. *Am. J. Cardiol.*, 74: 298-300.
27. Koepchen HP. (1984) History of studies and concepts of blood pressure waves, In: Miyakawa K, Mechanisms of blood pressure waves. Tokyo, Springer-Verlag, 3-23.
28. Cowan MJ, Kogan H, Burr R, Hendershot S and Buchanan L. (1988) Power spectral analysis of heart rate variability after biofeedback training. *J. Electrocard.*, 23 Supplement: 85-93.
29. Kitney RI. (1983) Heart rate variability in normal adults, In: Grossman P, Janssen KHL, and Vaitl D, Cardiorespiratory and Cardiosomatic Psychophysiology. New York and London, Plenum Press, 83-99.
30. Winfree AT. (1967) Biological rhythms and the behavior of populations of coupled oscillators. *J. of Theor. Biol.*, 16: 15-42.
31. Stancak A, Pfeffer D, Hrudova L, Sovka P and Dostalek C. (1993) Electroencephalographic correlates of paced breathing. *Cognitive Neurosci. Neuropsyh.*, 4 (Neuro Report): 723-726.
32. Taylor I, Duthie HL, Smallwood R, Brown BH and Linkens DA. (1974) The effects of stimulation on the myoelectrical activity of the rectosigmoid in man. *Gut*, 15: 599-607.
33. DeBeneditts G, Cigada M, Bianchi A, Signorini MG and Cerutti S. (1994) Autonomic changes during hypnosis: a heart rate variability power spectrum analysis as a marker of sympatho-vagal balance. *Int. J. Clin. Exp. Hypnosis*, XLII(2): 140-152.
34. Strogatz SH and Stewart I. (1993) Coupled oscillators and biological synchronization. *Scientific American.* December:102-109.
35. Pippard AB. (1978) The physics of vibration, London, Cambridge University Press.
36. McCraty R, Atkinson M and Tiller WA. (1995) New electrophysiological correlates associated with intentional heart focus. *Subtle Energies*, 4(3): 251-268.
37. Hatch JP, Borcherding S and Norris LK. (1990) Cardiopulmonary adjustments during operant heart rate control. *Psychophysiol.*, 27(6): 641-647.
38. Singer DH, Martin GJ, Magid N, Weiss JS, Schaas JW, Kehoe R, Zheutlin T, Fintel DJ, Hsieh AM and Lesch M. (1988) Low heart rate variability and sudden cardiac death. *J. Electrocard.*, (Supplemental issue): S46-S55.
39. Wiesenfeld K and Moss F. (1995) Stochastic resonance and the benefits of noise: from ice ages to crayfish and squids. *Nature*, 373: 33-36.
40. Poponin V. (1994) Nonlinear stochastic resonance in weak EMF interactions with diamagnetic ions bound within proteins, In: Allen MJ, Cleary SF, and Sower AE, Charge and field effects in biosystems. New Jersey, World Scientific, 306-319.
41. Walleczek J. (1992) Field effects on cells of the immune system: the role of calcium signaling. *Fed. Amer. Soc. Exp. Biology*, 6: 3177-3185.
42. Liovitz TA, Krause D and Mullins JM. (1991) Effect of coherence time of the applied magnetic field on ornithine decarboxylase activity. *Biochem. Biophys. Res. Com.*, 178: 262-265.
43. Sanders JS, Mark AL and Ferguson DW. (1989) Importance of baroreflex in regulation of sympathetic responses during hypotension: Evidence from direct sympathetic nerve recordings in humans. *Cir.*, 79: 83-92.
44. Eckberg DL, Rea RF, Anderson KO, Hender T, Pernow J, Lundberg JM and Wallin BG. (1988) Baroreflex modulation of sympathetic activity and sympathetic neurotransmitters in humans. *Acta. Physiol. Scand.*, 133: 221-231.
45. DeBoer RW, Karemaker JM and Strackee J. (1987) Hemodynamic fluctuations and baroreflex sensitivity in humans: a beat-to-beat model. *Am. J. Physiol.*, 253(Heart Circ. Physiol.): 680-689.
46. Brooks D, Fox P, Lopez R and Sleight P. (1978) The effect of mental arithmetic on blood pressure variability and baroreflex sensitivity in man. *Proceedings of the Physiological Society*, 280: 75-76.
47. Robbe HWJ, Mulder LJM, Ruddel H, Langewitz WA, Veldman JBP and Mulder G. (1987) Assessment of baroreceptor reflex sensitivity by means of spectral analysis. *Hyperten.*, 10: 538-543.
48. Bristow JD, Honor AJ, Pickering TG and Sleight P. (1969) Cardiovascular and respiratory changes during sleep in normal and hypertensive subjects. *Cardiovas. Res.*, 3: 476-485.
49. Bertinieri G, Rienzo MD, Cavallazzi A, Ferrari AU, Pedotti A, Zanchetti A and Mancia G. (1987) Baroreceptor-heart rate reflex studied in normotensive and essential hypertensives by beat-to-beat analysis of 24-hour blood pressure and heart rate. *J. Hyperten.*, 5 (Suppl. 5): 5333-5335.