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# Head-Heart Entrainment: A Preliminary Survey

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## Abstract

This preliminary survey deals with experimental observations on the degree of entrainment exhibited between heart rate variability (HRV), respiration and electroencephalograph (EEG) recordings for 5 subjects, trained in the use of a particular inner self-management technique, as they change their mode of heart function through various states of order. As the heart approaches its first major ordered mode of functioning (entrainment), both the sympathetic and parasympathetic branches of the autonomic nervous system shift their power into the mid frequency range ( $\sim 0.1$  Hz) in the HRV power spectrum which is associated with the baroreceptor feedback loop between the heart and brain. One then sees frequency pulling of the respiratory system towards this mid frequency range, until frequency-locking of the HRV waveform and respiration rate occurs. Thereafter, the signal amplitude in the  $\sim 0.1$  Hz range of the brainwaves begins to increase significantly. Strong cross-correlation functions are found to exist between these pairs of biological oscillators. However, the brain wave signals from different areas of the brain don't all frequency-lock with the baroreceptor signal. The auxiliary data indicates that there is much hidden complexity yet to be elucidated. Evoked potential data reinforces some of the major findings.

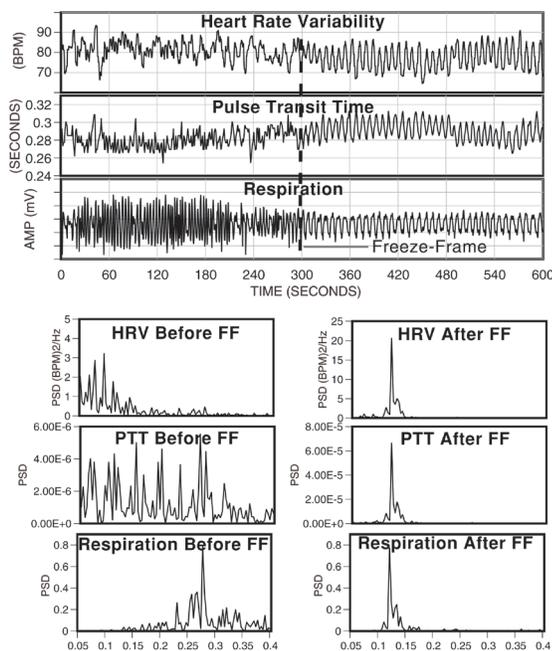
## Introduction

A number of physiological systems have been identified as exhibiting nonlinear oscillatory interaction phenomena; these include the sinoatrial node in the heart<sup>1</sup>, the respiratory system<sup>2</sup>, synchronization of nonlinear biochemical systems<sup>3</sup>, coupling in embryonic heart cells<sup>4</sup> and the digestive system<sup>5</sup>. Although these physiological systems clearly perform different functions, for each system the concept of synchronization or entrainment underlies its dynamic behavior. Early modeling of these systems involved a linear approach; however, many of the observed data do not fit a linear model. Therefore, in recent years, nonlinear modeling has been employed<sup>6</sup>. There are important differences between linear and nonlinear systems. For example, when two linear oscillatory systems operating at different frequencies are coupled, beating occurs and the resulting output contains frequencies which directly correspond only to the modes of oscillation of the individual systems (fundamental, sum, and difference frequencies). However, when the oscillators are nonlinear, the coupling causes the

two oscillators to lock into a common frequency. As the frequency difference between the two nonlinear systems is reduced, a point is reached where the combined system output suddenly consists of only a single dominant frequency. This is called "frequency selective entrainment." Another nonlinear phenomenon, called "frequency-pulling," can arise when the amplitude of one of the oscillators is insufficient to cause full entrainment but is capable of pulling or displacing the frequency of the other oscillator. This has been observed in a number of physiologic systems, e.g., electromyograph signals from the smooth muscle of the arterial system and the gut as well as the interaction between respiration and heart rate variability. This is a complex subject which cannot be covered in the space allotted here and interested readers are referred to the book by Grossman, et al.<sup>7</sup> In this study we are reporting on a similar entrainment phenomenon occurring between heart rate variability (HRV), respiration rate and very low frequency (VLF) electroencephalograph (EEG) recordings. Previous

studies have demonstrated a special relationship between respiration rate and high frequency EEG<sup>8</sup>.

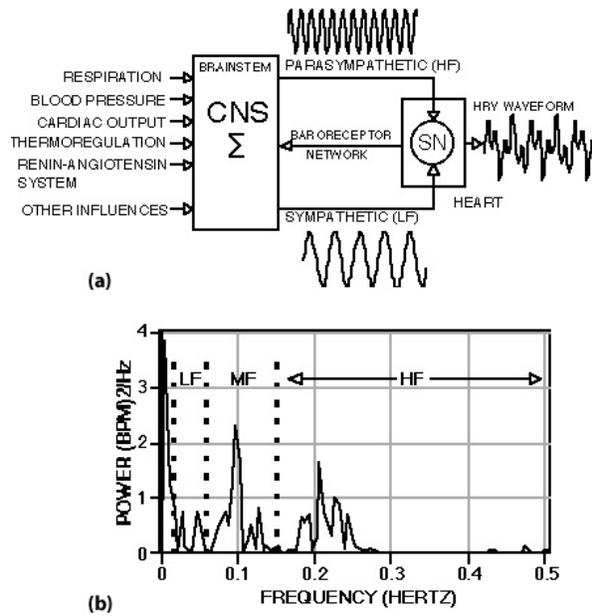
In our previous studies of the relationship between HRV, respiration rate, blood pressure waves and other somatic systems, we reported that when one is sincerely experiencing positive emotional states, there is a tendency for systems to naturally entrain and, further, that this entrainment process can be facilitated by specific techniques that shift conscious attention to the area around the heart (Freeze-Frame)<sup>9-12</sup> and/or by specifically designed music<sup>13</sup>. An example of entrainment between HRV, pulse transit time (PTT) and respiration rate is shown in *Figure 1*. A shift in perception and a greatly increased intuitive awareness has also been subjectively observed in many subjects when entrainment occurs.



**Figure 1.** Three simultaneously recorded body information channel responses to this subject enacting a “Freeze-Frame” (FF) and shifting to a state of appreciation at around 300 sec., (I) real time data for HRV, PTT and respiration. (II) powerspectra for the before-FF condition and (III) power spectra of the after-FF condition.

In all of these interesting considerations, one question that compels attention is, “Is there a 0.1Hz oscillator in the brain?” Another is, “Is any VLF signal in the brainwaves associated with electromagnetic (EM)

radiation from the heart or is it mainly nerve linked?” Still another is, “Are there pacemaker cells in the brain that like to function systematically with ~0.1 Hz oscillations and, if not, where does this stimulus come from?” Finally, the issue of the perceptual changes needs to be understood.



**Figure 2.** Illustration of the primary nervous system links between the brain and heart. Note this is a two-way system. Figure 2(b) shows a typical heart rate variability power spectrum divided into the three frequency bands. The low frequency band is a measure of mostly sympathetic activity, the mid frequency band is due to a mixture of both sympathetic and parasympathetic and gives a relative measure of the nerve traffic in the baroreceptor system, and the high frequency band is purely parasympathetic activity.

In order to facilitate understanding of the data reported herein, a brief review of the interactions of the heart and brain is necessary for the unfamiliar reader. *Figure 2a* is a simplified block diagram illustrating the two-way communication and feedback system between the heart and brain. The sympathetic and parasympathetic branches of the autonomic nervous system (ANS) influence the sinus node of the heart and vascular systems thereby modulating heart rate and blood pressure. Changes in heart rate and blood pressure are fed back to the brain via the baroreceptor system. The baroreceptor input to the brain has numerous effects on brain function. For example, when one’s mental or emotional state is causing the

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sympathetic system to be overdriven in stressful situations, the baroreceptor feedback inhibits sympathetic outflow, increases parasympathetic neuronal activity<sup>7</sup>, causes brain wave slowing<sup>14</sup> and cortical inhibition<sup>15</sup> in order to protect the overall system. This feedback loop or connection between the heart and brain stem is thought to be responsible for the well known 10 second rhythm or 0.1 Hz frequency peak seen in the HRV power spectrum<sup>6</sup>. The baroreceptor input to the brain is also responsible for the 0.1 Hz rhythms seen in reticular neuronal activity in the brain stem and the cardiac rhythms seen in the sympathetic outflow to the body<sup>7</sup>. The reticular neuronal network is a multifunctional system controlling respiration, cardiovascular and somatomotor systems, as well as the degree of cortical activity<sup>7</sup>.

*Figure 2b* illustrates the power spectrum of a 5-minute HRV waveform. The HRV power spectrum has been divided into three frequency ranges for our studies, LF (0.01 to 0.05 Hz), MF (0.05 to 0.15 Hz) and HF (0.15 to 0.5 Hz)<sup>16</sup>. The MF region can be used to discriminate the power in the baroreceptor feedback loop, which is responsible for beat-to-beat blood pressure control<sup>17</sup>. Power in the MF region can be due to parasympathetic or sympathetic outflow from the brain or due to a mixture of both<sup>16, 18</sup>. Power in the MF region of the HRV spectrum has also been correlated to nerve traffic in the baroreceptor feedback loop back to the brain<sup>19</sup>. The HF region is associated with only parasympathetic activity while the LF region is associated with mostly sympathetic activity.

We have developed a simple method termed the “Freeze-Frame method” (FF)<sup>12</sup> for consistently producing beneficial shifts in parasympathetic tone and sympathovagal balance. This has been tested in both normal individuals<sup>20</sup> and in subjects with a number of pathological states<sup>21</sup>. The technique has been successfully employed in a number of applications to reduce stress and emotional reactivity. The application of the FF technique readily leads to ordered states of heart function, one of which is the entrainment mode which has been described in detail elsewhere<sup>9</sup>.

In the entrainment mode of heart function, power in the MF region of the HRV frequency spectrum is greatly increased indicating increased neural traffic in the baroreceptor system. The entrainment between the HRV waveform and the low frequency portion of the EEG reported here was observed in subjects who have been practicing the FF technique for some time and, thus, can consistently demonstrate an increased ratio of time in the heart entrainment mode and shift to this mode at will. It appears that, as one develops the ability to maintain the HRV entrainment mode, the brain is also brought into entrainment with the heart rhythms. Subjective statements, from several hundred newly trained practitioners, indicate that a significant shift in perception and awareness is associated with using this technique. Therefore, the present study set out to explore the electrophysiological correlations between heart and brain functions.

Prior to starting the practice of FF, the subjects, whose data is shown herein, did not demonstrate either significant LF activity in the EEG, an ordered mode of heart function or entrainment between any biological oscillators of the body.

### **Experimental Protocol**

Five individuals trained in the Freeze-Frame (FF)<sup>12</sup> technique were seated in comfortable, high backed chairs, to minimize postural changes, fitted with ECG and EEG electrodes, respiration belt, and ear and finger pulse transducer sensors. Prior to each session, subjects were informed of the tasks they were to perform and asked to refrain from talking, falling asleep, exaggerated body movements or intentionally altering their respiration. The subjects were carefully monitored to ensure that there were no exaggerated respiratory or postural changes during the session. No biofeedback aids were used in this study, and none of the subjects had any prior experience with biofeedback training. The subjects were monitored, one at a time, using a 15 minute baseline period followed by a 5 minute FF period. Briefly stated, the Freeze-Frame technique instructs subjects to consciously disengage from stressful mental and emo-

tional states by shifting attention to the heart, which most people associate with positive emotions, and focus on sincerely feeling appreciation or a similar positive emotion toward someone or something (in contrast to solely mentally recalling or visualizing a past positive experience). Previous experience with this technique has shown that it is an effective method for shifting the focus of attention away from current stressors. The conscious shifting of awareness to a positive emotional feeling state appears to be a key to the successful application of this maneuver.

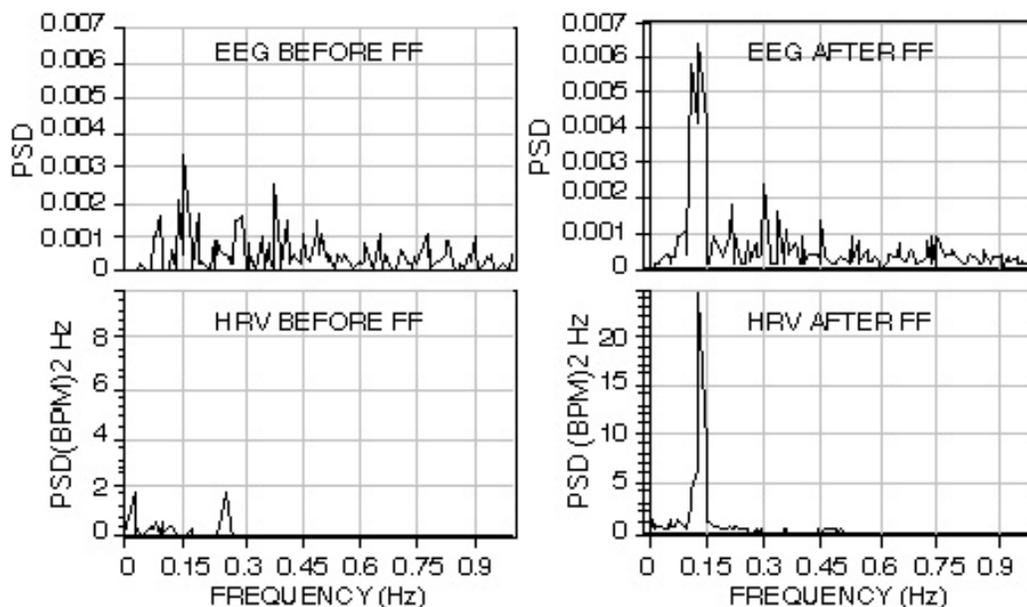
Ag/AgCl disposable electrodes were used for all bipolar ECG measurements. The positive electrode was located on the left side at the 6th rib and the reference was placed in the right supraclavicular fossa. Grass model 7P4 amplifiers were used for ECG amplification. The HRV waveform is in the form of 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 original ECG signal sampled at 256 Hz and Fast Fourier Transformed (FFT).

The EEG was amplified with Grass model P5 amplifiers, and electrodes were attached according to the

International 10-20 system at the O1, O2, FP1, FP2, CZ, T5, T6, T7 and T8 locations. The LF filters were set to the 0.15 setting. Respiration was monitored with a Resp-EZ piezoelectric belt around the chest. A Grass model 80 cardiac microphone was used to monitor the blood pressure wave for calculation of pulse transit time (PTT). The PTT interval is the time between the peak of the R-wave of the ECG and the appearance of the pulse wave associated with that same cardiac contraction at the index finger on the left hand. A UFI model 1020 photoelectric pulse transducer was used to obtain the pulse wave arrival at the right ear lobe.

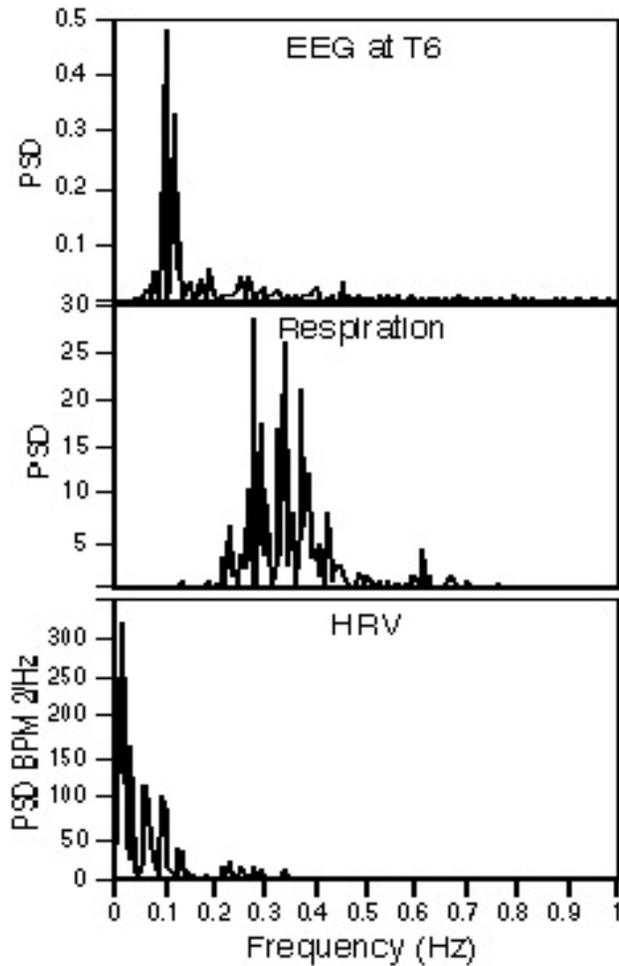
## Results

Figure 3 provides simultaneous HRV and EEG power spectral density (PSD) data from a subject during the 5-minute period immediately prior to the FF-intervention and the 5-minute period immediately after the initial FF-intervention with continued focus on sincerely feeling a positive emotion. Note that, before the FF, the EEG data recorded from the CZ point has only nominal activity in the  $\sim 0.1$  Hz range. However, after the FF intervention, when the subject is in the entrained state, the HRV entrainment signature suddenly appears in the EEG.



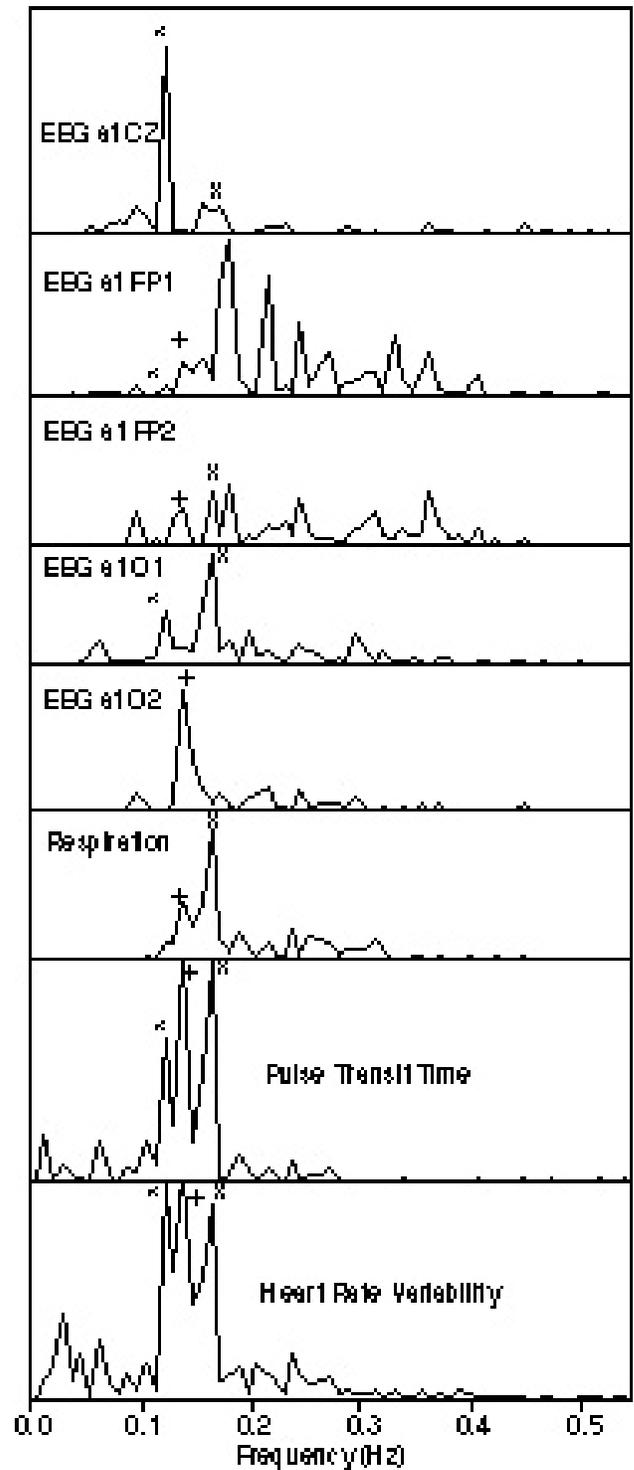
**Figure 3.** Data showing the appearance of a large peak in the EEG (CZ), which is frequency locked to the HRV entrainment frequency after entrainment mode was entered by this subject.

Further, we have also observed that when the entrainment state is practiced and maintained by a subject for increased time ratios, the very low frequency (VLF) peak can occur in the EEG even when in the absence of HRV entrainment. *Figure 4* illustrates this point.



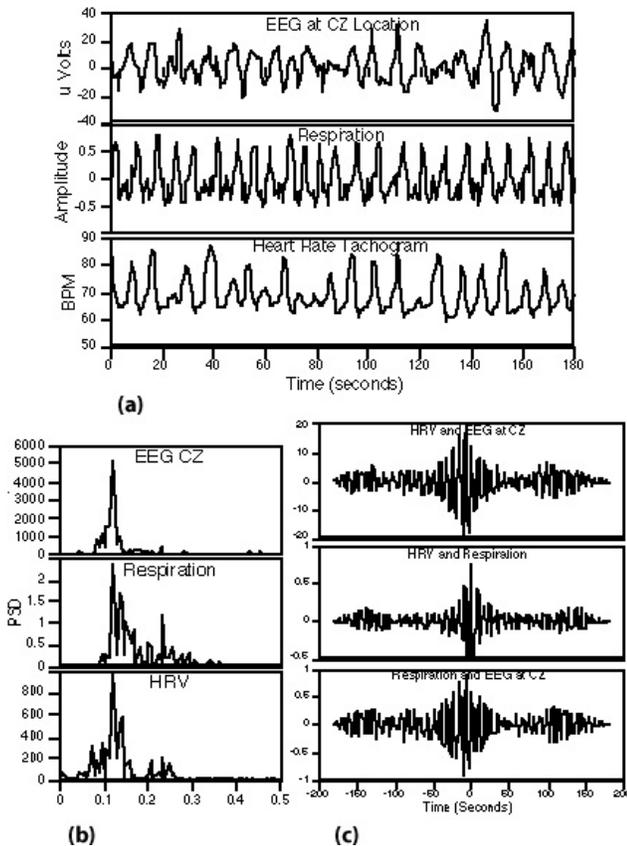
**Figure 4:** Illustration of the presence of a high amplitude peak in the EEG around the .01 Hz frequency independent of HRV entrainment and respiration. We have only observed this in individuals after they have been practicing Freeze-Frame extensively.

*Figure 5* provides an example of a subject whose heart function is not fully entrained. Note that the three main HRV spectrum peaks (lowest plot) appear non-linearly amplified in both the respiration and PTT data. However, some, but not all, of the HRV peaks are present in the EEG data taken from various locations.



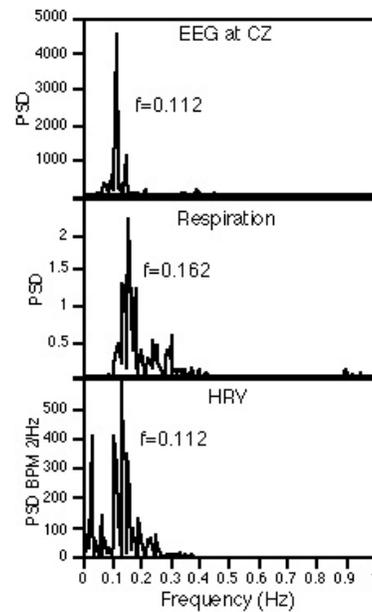
**Figure 5.** Five EEG channels, respiration, PTT, and HRV power spectra during a near entrainment mode condition. The \*, + and x indicate the frequencies are the same.

Figure 6 data is found when this subject is in the fully entrained mode. Figure 6a shows filtered EEG (CZ), respiration and HRV. Figure 6b shows PSD plots for each time wave while Figure 7c shows the cross correlations for each of the oscillator pairs, HRV and EEG, HRV and respiration, plus EEG and respiration. A high degree of coupling between these three biological oscillator systems is demonstrated when a strongly entrained heart function mode is present.



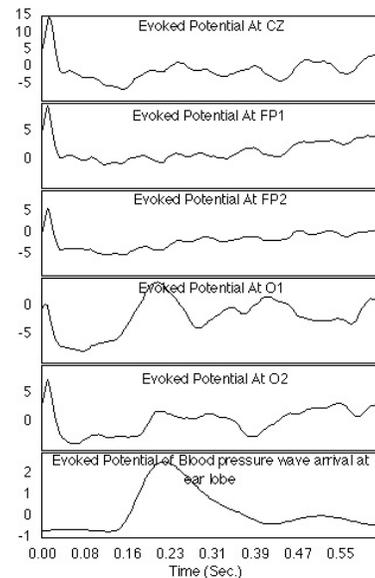
**Figure 6.** (a) The EEG, respiration and HRV time-domain waves, (b) the corresponding PSD plots of the time waves and (c) the cross correlations between pairs of measurements.

Figure 7 presents an example of entrainment between the HRV and EEG (CZ) while the respiration is not yet fully entrained to the HRV or EEG. It is, however, being “frequency-pulled” toward the HRV frequency. This illustrates the two-way interaction between respiration and heart function. It is well known that respiration affects heart rate; however, it is less well understood that heart rate also affects respiration via the baroreceptor system<sup>22</sup>.



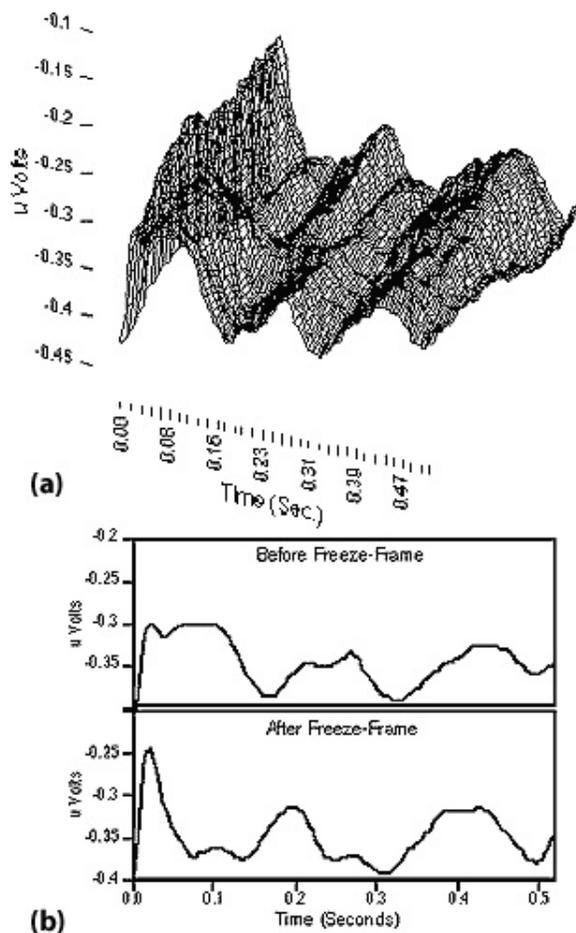
**Figure 7.** Data showing the appearance of a large peak in the EEG (CZ), which is frequency locked to the HRV entrainment frequency after entrainment mode was entered by this subject.

Figure 8 provides evoked potential plots from several specific brain locations. These all had a start time locked to the R-wave of the ECG. The bottom plot shows the ear-recorded pulse wave associated with this R-wave. Note that its maximum occurs 240 ms after the R-wave maximum.



**Figure 8.** The top 5 traces illustrate evoked potential plots, from different EEG recording locations, synchronized to the ECG R-wave recording. The bottom trace shows the evoked potential of the blood pressure wave also synchronized to the ECG R-wave.

Figure 9a shows an example of a waterfall plot of EEG (T6) evoked potentials for a 10 minute period. Each of the 38 traces in the plot consists of 180 trials. These evoked potentials were generated by averaging together background EEG synchronized to the peak of the R-wave of the ECG. During the first half of the plot the subject was in the normal state and then shifted to the entrainment state via the FF-intervention for the remainder of the time. Note that the first and last curves (Fig. 9b) of this waterfall sequence are significantly different from each other. The transition occurs at the FF point. These shifts in the EEG may be a key to understanding the shifts in perception and increased intuitive awareness reported by most people after practicing the Freeze-Frame technique.



**Figure 9a.** (a) Waterfall plot of EEG evoked potentials recorded at the T6 location. Note the shift in evoked potentials half way through the record. Figure 9 (b) shows the beginning and ending plots of the waterfall. This shift has been observed at all locations across the head.

## Discussion

In the last 25 years, a variety of new techniques have been introduced as alternatives to more traditional psychotherapies or pharmaceutical interventions for improving mental and emotional imbalances. In addition to the more conventional psychological approaches like cognitive restructuring and neurolinguistic programming, psychologists have employed several techniques from eastern cultures to “still the mind” during a focused meditation period. Yoga, for example, generally focuses on the breath or differing parts of the brain<sup>2</sup>, whereas Qigong focuses on the “Dan Tien” point (below the navel). HeartMath techniques, on the other hand, focus on the area of the heart in order to disengage from the racing mind or emotions and shift perception. It is interesting to note that all the above systems focus attention to areas of the body which are known to contain biological oscillators. The heart, brain and intestines<sup>5</sup> all have natural rhythms around 0.1Hz which is the entrainment frequency shown in *Figure 1*.

It appears that these three systems can operate in or out of sync with one another. Further, by the intentional focusing of attention on any one of these systems, their rhythm can be altered. This is at least true for the brain (meditation) and the heart (Freeze-Frame), and most likely true in the case of the gut (Qigong) as well, since the interaction of the sympathetic and parasympathetic nervous systems innervates and affects its rhythms<sup>23</sup>. Figure 2 shows an almost hundred fold increase in the MF signal power after the FF-intervention and a correlated 4 to 5 fold increase in the EEG signal power for that same frequency. If this EEG signal was associated with direct radiation from the heart, one would expect the increases to be in the ~1.0-1.5 Hz range (R-R wave frequency) rather than the ~0.1 Hz range (baroreceptor frequency). Our present hypothesis is that a strong and sustained increase in baroreceptor system activity leads to a greatly increased coupling between the heart (HRV) and the brain (EEG) via nerve conducted signals. Independent brain oscillator capability in the ~0.1 Hz range appears to exist as illustrated in *Figure 2a* before

FF; however, strong baroreceptor signals appear to be able to resonate these brain oscillation modes to greater amplitudes.

The data of [Figure 4](#) also supports this view in that, for some individuals, very large power density is present in this frequency range even when the heart is not functioning in the entrainment mode. Perhaps one of the lessons to be learned here is that one should not consider the electrical output of the brain in isolation from the other major biological oscillators of the body since they all form a coupled system.

Although one can certainly see how a strong  $\sim 0.1$  Hz signal traveling from the heart to the brain via the baroreceptor link might frequency-pull the sympathetic and parasympathetic branches of the ANS into this frequency range and also frequency-pull the respiratory system into the same range, it is not so clear where this  $\sim 0.1$  Hz baroreceptor signal originates.

We propose that [Figure 2a](#) needs to be altered to include an intentionality source, which exists at a more subtle level than the physical, and it is this source that pumps the initiating  $\sim 0.1$  Hz signal into the baroreceptor channel heading for the brainstem.

[Figure 10](#) provides a pictorial representation of this speculative modeling.

In the evoked potential study, the EEG was averaged, synchronized to the R-wave of the ECG as can be seen in [Figure 8](#). From the hemodynamics, the associated blood pressure pulse, seen with the ear lobe measurement, is detected in the evoked potential trace 240 ms later (see *bottom of Figure 8*).

This blood pressure pulse was clearly manifested in the O1 and O2 plots of [Figure 8](#) but not in the waterfall evoked potential traces of [Figure 9a](#) before the FF intervention.

After the FF intervention, a rather abrupt transition appeared in the waterfall traces with a fairly rapid shift to a trace that closely approximates that of the last trace in [Figure 9a](#). This contrast is apparent in [Figure 9b](#) which reproduces the first and the last trace of

[figure 9a](#). This data is very important in that it shows how rapidly the evoked potential can reflect changes in the functioning of the heart.

With the present experiments, we are unable to make any unequivocal statements concerning the presence or absence of pacemaker cells in the brain; however, the neural network appears capable of stable oscillation in the  $\sim 0.1$  Hz range.

Although the issue of the individual's perceptual change, that occurs in association with the entrainment mode of heart function, needs to be discussed, electrophysiological monitoring alone does not provide the appropriate data base for meaningful evaluation. Short term psychological tests are needed to discriminate the perceptual changes associated with the FF intervention experience. Although a single or several simultaneous sensory information inputs lead to a particular perception, and integration of a number of perceptions leads to awareness, the latter is only one facet or correlate of consciousness. Clearly, we have a long way to go before the full scope of head/heart entrainment can be understood.

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## About the HeartMath Institute

Incorporated in 1991 in Boulder Creek, Calif. by Doc Childre, the HeartMath Institute (HMI) is an innovative nonprofit 501 (c) (3) research and education organization that has developed simple, user-friendly mental and emotional self-regulation tools and techniques that people of all ages and cultures can use in the moment to relieve stress and break through to greater levels of personal balance, creativity, intuitive insight and fulfillment. HMI research has formed the foundation for training programs conducted around the world in many different types of populations, including major corporations, government and social-service agencies, all branches of the Armed Forces, schools and universities, hospitals and a wide range of health-care professionals. The tools and technologies developed at HMI offer hope for new, effective solutions to the many daunting problems that currently face society, beginning by restoring balance and maximizing the potential within each of us.

### **HeartMath Institute's Mission (HMI)**

Help people bring their physical, mental and emotional systems into balanced alignment with their heart's intuitive guidance. Provide pathways for achieving fulfillment by becoming who we truly are – heart-empowered beings who choose the way of love, demonstrated through our compassion, care and appreciation for the well-being of ourselves, each other and the earth.

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