Heart Rate Variability During Meditation

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Abstract—**This paper describes a study of heart rate variability, specifically how the variability differs in a subject before and during meditation. The results clearly show that the heart rate sequence of all subjects exhibited increased mean value, increased variability, and increased power in the Low Frequency band. This can be interpreted as evidence of a change in the balance of the autonomic nervous system induced by meditation.**

I. Introduction

The fact that heart rate variability can be easily measured noninvasively makes it an attractive signal to use in the study of human physiological response to different stimuli [1], [2]. Heart rate variability (HRV) is the change in the time interval between heartbeats, from beat to beat. It is controlled by the autonomic nervous system, which also controls many other vital functions within the body. This system is divided into two parts, the sympathetic and the parasympathetic. The sympathetic branch, in a simplified sense, increases heart rate and the parasympathetic branch decreases heart rate. Thus, the observed heart rate variability is an indicator of the dynamic interaction and balance between these two branches of the system.

HRV data is usually analyzed in terms of its power spectral density (PSD). The PSD reveals the relative strengths of the frequency components of the signal. Frequencies in the range 0.0033 to 0.04 Hz (VLF) are associated with parasympathetic activity; frequencies from 0.15 to 0.4 Hz (HF) are associated with sympathetic activity. The intervening band (LF) is a mixture of the two influences [1]. (Note that this interpretations of the frequency bands is not accepted by the entire cardiology community.)

Recently, HRV data was collected from subjects before and during meditation, in the hope of gaining insight into the autonomic response induced by the meditative state [3]. The goal of this paper is to present a characterization of this data in terms of power spectral density, and to compare the HRV prior to meditation with HRV during meditation.

II. Methodology

A. Preprocessing

The data consists of eight time series, two for each of four different subjects. The subjects recorded their heart rate for about 15 minutes of quiet resting (the first series) followed by about 15 minutes of Kundalini Yoga meditation (the second series). This type of meditation involves chanting and breathing exercises while seated in a cross-legged position. All four subjects were advanced practitioners.

Each time series consists of a sequence of instantaneous heart rates (beats per minute) and a time stamp for each value (seconds) giving the elapsed time since the start of the recording session. The heart rate was calculated as:

$$HR(n) = 1/(ET(n) - ET(n-1)) * 60 \quad (1)$$

where ET is the elapsed time.

The sequences were therefore sampled at an irregular rate. To correct this, I resampled each sequence at 2 Hz using a Gaussian window of length 2 (algorithm supplied by Dr. James McNames.) This sampling rate is greater than the Nyquist rate for the frequency band of interest (0 to 0.4 Hz). The average samples/second over each original sequence ranged from 0.74 to 1.64. I did not want to oversample, because the resampling process is just interpolating between the actual sample points (i.e. no additional actual data is generated by oversampling, only additional interpolated points.) The resampled series are shown together in Figure 1.

The sample means of each series were not equal (as expected, due to individual variation in average heart rate.) Of note was the fact that for each subject, the sample mean of the series during meditation was significantly higher than the mean of the series before meditation. Since the focus of my analysis was heart rate variability, I removed the sample means prior to calculating the variance, autocorrelation and power spectrum, so that comparisons could be made between the different series.

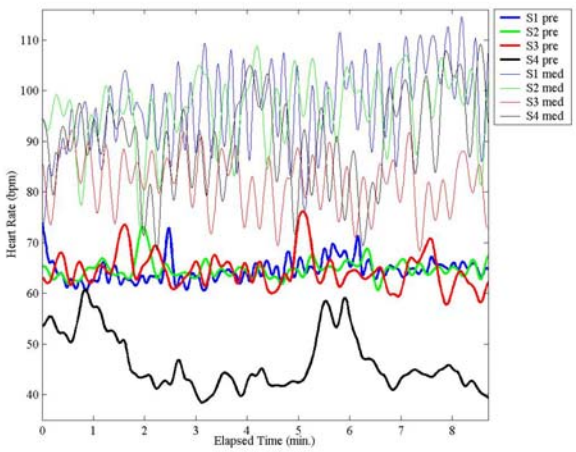

Fig. 1. Heart rate time series for four subjects before and during meditation.

B. Analysis

The variance of each sequence was calculated using the estimator:

$$\sigma^2_x = 1/(N-1) * \Sigma_N [x(n) - \mu_x]^2 \qquad (2)$$

where σ^2_x and μ_x are the estimated variance and estimated mean, respectively. The variance of this estimator is approximately 2/(N-1) times the square of the true variance. Since the size of each sequence was greater than 1000, the variance of the estimator should be reasonably small.

The autocorrelation of each sequence was estimated as:

$$r_x(l) = 1/N * \Sigma_{N-l}x(n)x(n-l) \text{ for } 0 \le l \le N-1, \text{ and 0 otherwise} \qquad (3)$$

This estimate is biased; however the bias is small for lags much smaller than N [5]. Therefore I used a maximum lag of L=250 in my calculations, where L < N/4 for all the samples.

To estimate the power spectrum of each sequence, I used the Blackman-Tukey approach [4]. The theory of this approach is to reduce the variance of the natural estimator (simply taking the DFT of the estimated autocorrelation) by windowing the estimated autocorrelation prior to transformation into the frequency domain. Although this approach reduces the variance of the power spectrum estimate, there is a corresponding loss of resolution. Both variance and resolution depend on the choice of the window length. I used a window length of 255, after experimenting with other lengths, to achieve an acceptable resolution without introducing too much variance. The window used was a Parzen window normalized to have a maximum value of unity.

III. Results

The variability in the time domain of each subjects' heart rate is shown in Fig. 2 - 5. The normalized autocorrelation is plotted for each subject in Fig. 6 - 9. Finally, the estimated power spectrum for each subject before and during meditation is shown in Fig. 10 - 13.

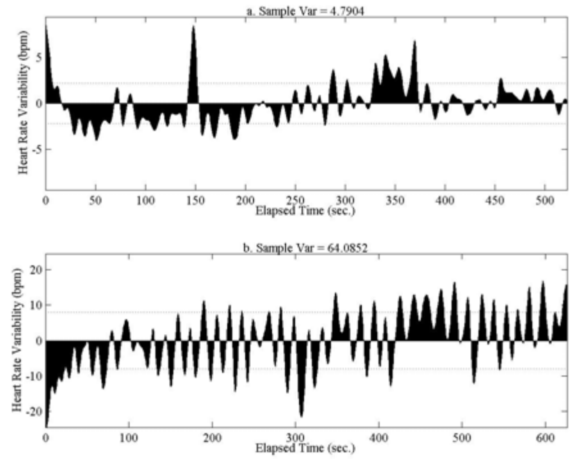

Fig. 2. Heart Rate Variance of Subject 1. a) Before meditation. b) During meditation.

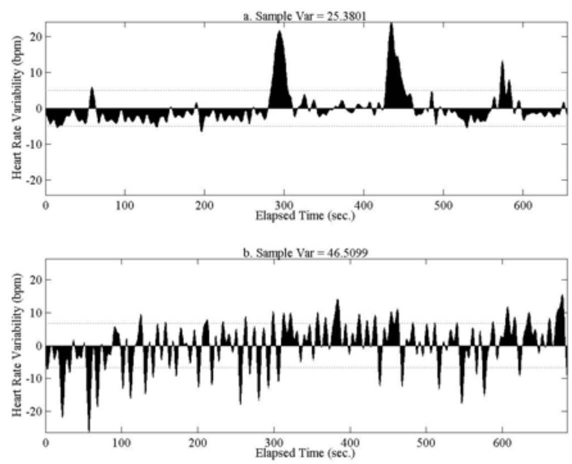

Fig. 3. Heart Rate Variance of Subject 2. a) Before meditation. b) During meditation.

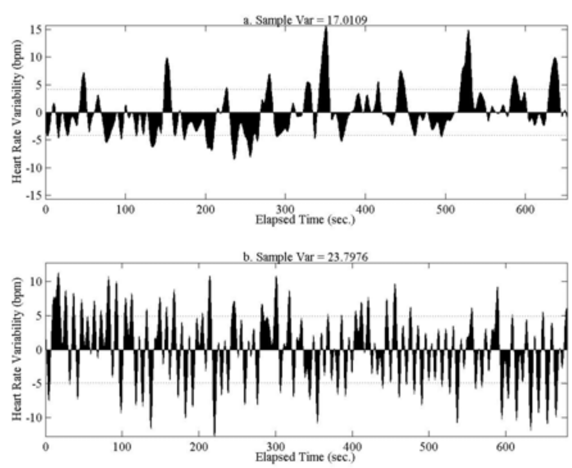

Fig. 4. Heart Rate Variance of Subject 3. a) Before meditation. b) During meditation.

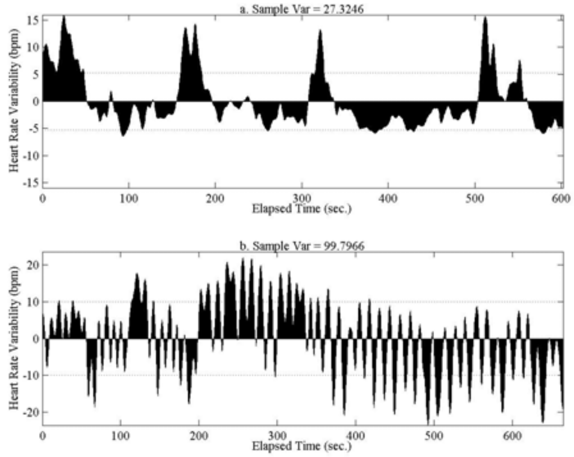

Fig. 5. Heart Rate Variance of Subject 4. a) Before meditation. b) During meditation.

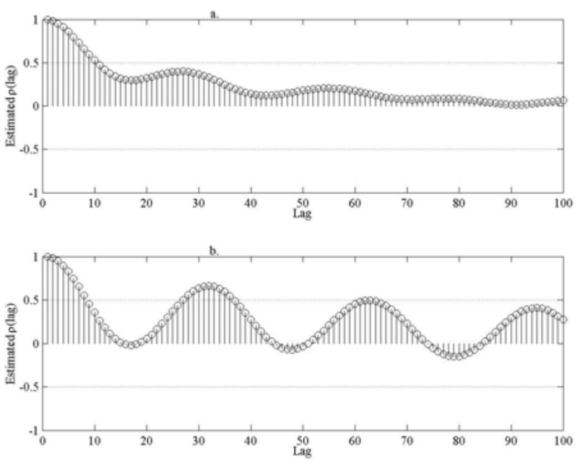

Fig. 6. Autocorrelation Function (ACF) of Subject 1. a) Before meditation. b) During meditation.

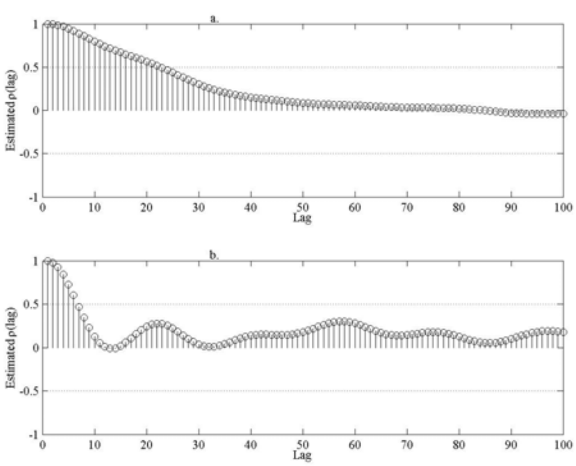

Fig. 7. Autocorrelation Function (ACF) of Subject 2. a) Before meditation. b) During meditation.

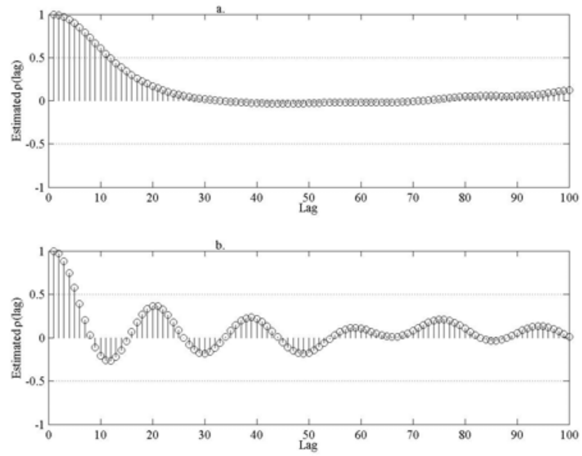

Fig. 8. Autocorrelation Function (ACF) of Subject 3. a) Before meditation. b) During meditation.

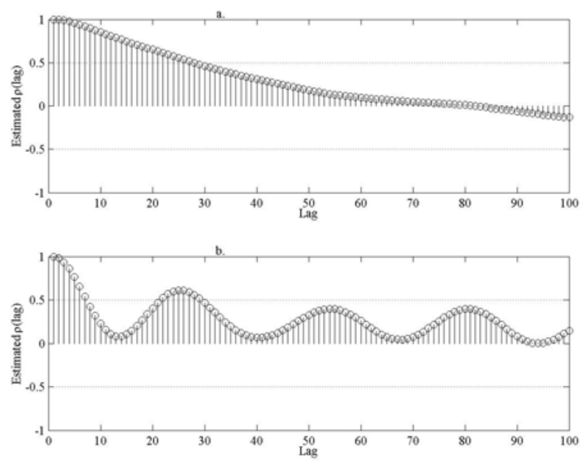

Fig. 9. Autocorrelation Function (ACF) of Subject 4. a) Before meditation. b) During meditation.

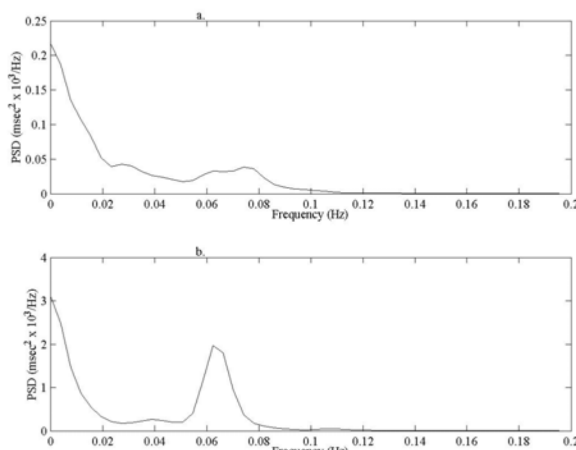

Fig. 10. PSD of Subject 1. a) Before meditation. b) During meditation.

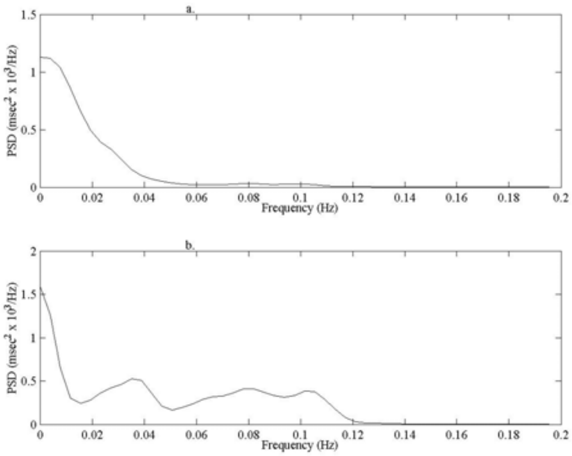

Fig. 11. PSD of Subject 2. a) Before meditation. b) During meditation.

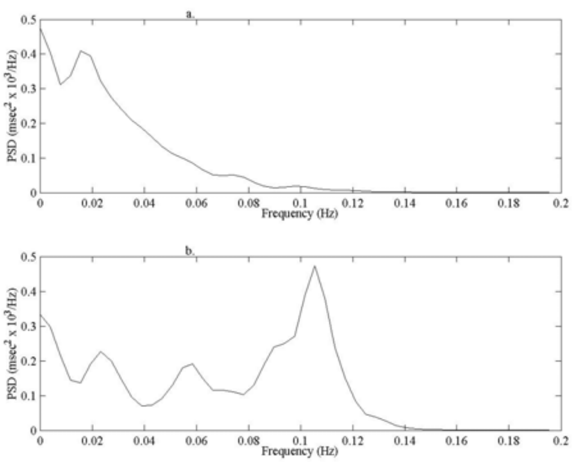

Fig. 12. PSD of Subject 3. a) Before meditation. b) During meditation.

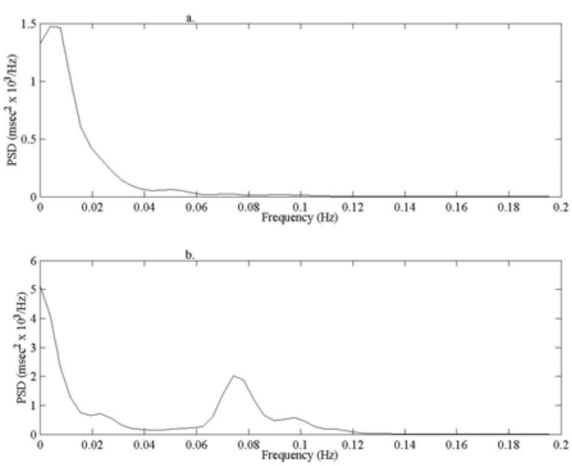

Fig. 13. PSD of Subject 4. a) Before meditation. b) During meditation.

IV. Discussion

First, the issue of stationarity and ergodicity as it pertains to this study should be addressed. The biological process that produces a heart rate time series is not really stationary, and therefore not ergodic. However, the process can be considered locally stationary over short time segments during which time the mechanisms responsible for heart rate modulation are assumed to remain unchanged. Since the time series used in this study are all less than 12 minutes in length, the assumption of local stationarity is justified. Ergodicity may be assumed if the population in question is limited to advanced practitioners of Kundalini meditation.

In the time domain, the variance of the heart rate during meditation was significantly higher than before meditation for all subjects. This reflects additional cyclic components present in heart rate modulation mechanisms during meditation. These cyclic components are also evident in the estimated autocorrelation sequences, which exhibit sinusoidal patterns.

In the frequency domain, the total power in the sequences recorded during meditation was higher than in those recorded before. The additional power appeared in the LF band (0.04 – 0.15 Hz). This seems to indicate that the balance between the two branches of the autonomic nervous system is changed by the act of meditating. However, due to the variance and low resolution of the estimator, the precise locations and power of the peaks evident in this range cannot be inferred.

All of the series, both before and during, exhibit a concentration of power in the VLF band (< 0.04 Hz). It represents a non-harmonic component of the heart rate modulation mechanism and is not well understood [2]. For sequences of such short duration as those used in this study, no clear interpretation can be attributed to this.

V. Conclusions

This study revealed definite changes in the heart rate variability of the subjects during meditation, quantified as an increase in power in the LF band. Although more precise conclusion cannot be drawn, the results strongly indicate that further inquiry into the physiological effects of meditation would be fruitful in increasing our understanding of the mind-body connection.

References

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