Analysis of Heart Rate Variability during Meditation by a Pattern Recognition Method

Sukanya Phongsuphap[1], Yongyuth Pongsupap[2]

[1]Faculty of Information and Communication Technology, Mahidol University, Bangkok, Thailand
[2]National Health Security Office, Nonthaburi, Thailand

Abstract

The main objective of this study is to investigate patterns of heart rate variability during concentration meditation to understand its effects on health. Our method consisted of three major stages: Signal acquisition, Feature extraction, and Classification. The input signals are RR interval signals which were collected from 105 subjects. By K-mean clustering method, the signals could be classified into 3 clusters corresponding to state of quiet mind (Samadhi state), intermediate state, and normal state. The results indicate that meditation and ordinary quiet sitting have significantly different effects on Autonomic Nervous System. In addition, it should be noted that meditation has different effects on health depending on frequency of the resonant peak that each meditator can achieve.

1. Introduction

Meditation appeared more than five thousand years ago. It was developed and practiced continuously. Up until now there are many types of meditation techniques that are available for practical uses for any people regardless of their religions. Although there are various types of meditation techniques, all of them can be broadly classified into two basic groups: Concentration meditation and Insight meditation [1]. Concentration meditation is the technique that focuses the attention on one thing, which mostly is the breath, in order to still the mind. As the meditator focuses his/her awareness on the breath, his/her mind becomes absorbed in the rhythm of inhalation and exhalation which may lead to the state of quiet mind called the Samadhi state. The Samadhi state is the state of successful concentration meditation. On the other hand, insight meditation involves opening the attention to become aware of the continuously passing of sensation and feeling without becoming involved in thinking about them. In this work, we focus on investigating the effects of meditation practices from the techniques based on the concentration meditation approach.

Heart rate variability (HRV) [2] is the change in the time interval between heartbeats. It is controlled by the Autonomic Nervous System (ANS), which also controls many other vital functions within the body. The HRV is an indicator of the dynamic interaction and balance between the sympathetic and parasympathetic systems. The HRV can be measured noninvasively. Therefore, it becomes an attractive measure to use in the study of the ANS response to different stimuli, e.g., [3], [4]. HRV measures are usually divided into two basics categories that are time domain analysis measures and frequency domain analysis measures [2]. There are a number of researchers had studied the effects of meditation on the health based on HRV analysis, e.g., [5], [6], [7], [8], [9]. However, we still gained little knowledge about this.

This paper aims to investigate patterns of heart rate variability during concentration meditation from various HRV measures by a pattern recognition method to gain more understanding of effects of concentration meditation on autonomic nervous system.

2. Methodology

Our method consists of three major stages: signal acquisition, feature extraction and classification. Details are elaborated below.

2.1. Signal acquisition

RR interval signals were collected from 105 subjects by using Polar 810/810i. During meditation practice, the subjects sat in a cross-legged position and kept their eyes closed as they were accustomed to doing during their meditation practices. Subjects were first instructed to sit quietly for 5 minutes. Pre-meditation measures were taken during this time. After that, they were instructed to perform meditation for at least 15 minutes. The subjects were asked to meditate everyday for about 4 weeks. During ordinary quiet sitting, the subjects were also instructed to sit quietly for 10-20 minutes in a cross-legged position, which is the same posture as the subjects do during meditation practice.

After finishing meditation, they had to report if they could achieve the Samadhi state or not, and report about their feelings or states of mind (e.g., refresh, relax, neutral, bore, worry, stress, etc.) during the meditation practice. In the case that the Samadhi state was achieved, the intervals during which each subject reported that he/she concentrated on meditation (other thoughts did not occur) were labeled as the segments of the Samadhi state.

2.2. Feature extraction

The RR interval data were analyzed both in time domain and frequency domain.

In time domain analysis, six HRV measures are considered in our experiments. Most of them are the basic HRV measures recommended by the Task Force of the European Society of Cardiology and the North American of Pacing and Electrophysiology [2]. They are the followings:

(1) **mRR**: Mean of all inter-beat intervals
(2) **mHR**: Mean of heart rates
(3) **sdNN**: Standard deviation of all inter-beat intervals
(4) **sdHR**: Standard deviation of heart rates
(5) **AR**: Autocorrelation of the RR interval signals
(6) **RMSSD**: Square root of the mean of the sum of the squares of differences between adjacent inter-beat intervals.

In frequency domain analysis, four basic HRV measures are investigated:

(1) **VLF**: Power spectrum in the very low frequency range, 0.003 - 0.04 Hz.
(2) **LF**: Power spectrum in the low frequency range, 0.04 - 0.15 Hz.
(3) **HF**: Power spectrum in the high frequency range, 0.15 - 0.4 Hz.
(4) **LF/HF**: Ratio between the power spectrum in LF range and the power spectrum in HF range.

The other measures that can be defined from these basic measures from both time domain and frequency domain are also investigated, for example, width of the highest spectral peak (**PeakW**), frequency of the highest spectral peak (**PeakF**), normalized VLF, normalized LF, normalized HF, etc.

2.3. Classification

Firstly, we performed an initial experiment to classify RR interval data into two categories of Samadhi state (Category I) and Non-Samadhi state (Category II) by using Fisher linear discriminant analysis [10]. The discriminant function (y) is given as

$$y = [\mathbf{m_1} - \mathbf{m_2}]^T \mathbf{S_p}^{-1} \mathbf{X} \qquad (1)$$

where $\mathbf{X}$ is the feature vector of an observed segment, $\mathbf{m_1}$ and $\mathbf{m_2}$ are the mean feature vectors of segments in Category I and Category II respectively, $\mathbf{S_p}$ is the pooled covariance matrix between two populations with n_1 and n_2 observations respectively.

The discriminant function (y) is compared to a midpoint (m) between the two populations. If $y > m$, the observed segment $\mathbf{X}$ is classified as belonging to Category I, otherwise classified to Category II.

We used the characteristics of RR intervals data obtained from the initial classification experiment as explained above to guide us in selecting features and determining initial centers for clusters. All of data will be classified into **K** groups by **K**-means clustering method. After that, the data in each cluster are investigated to summarize the characteristics of HRV measures in the Samadhi state and compare the differences to the Non-Samadhi state. **K**-means clustering algorithm was introduced by McQueen [11]. The procedure of this algorithm can be described as follows:

K-means Clustering algorithm:

(1) Select a number of clusters required (**K**).
(2) Allocate **K** points in feature space as cluster centers.
(3) Calculate the distance between all of the data points and each cluster center.
(4) Each item is assigned to a cluster based on the minimum distance.
(5) Recalculate the cluster centers from the feature vectors of the items assigned to each cluster.
(6) Repeat steps (3) to (5) for all the data, moving items between clusters as necessary.
(7) Stop when there is no further movement between the clusters.

3. Results

Experimental results are elaborated in this section including initial classification result and clustering result.

3.1. Initial classification result

We had performed an initial experiment to classify 250 segments of RR interval data including 133 segments from the Samadhi state and 117 segments from the Non-Samadhi state by Fisher discriminant function as explained in Section 2.3. We obtained 94.8% correct classification. The preliminary result indicated that the salient features of RR interval time series for discriminating the Samadhi state and the Non-Samadhi state were the regularity of the RR interval time series, the mean heart rate, and the spectral peaks in VLF, LF and HF ranges.

3.2. Clustering result

The result from the initial classification experiment led us to use the following seven features: mean heart rate (mHR), autocorrelation coefficient (AR), normalized VLF power spectrum, normalized LF power spectrum, normalized HF power spectrum, width of the highest spectral peak (PeakW), and frequency of the highest spectral peak (PeakF) for grouping the RR interval data. By using K-means clustering algorithm and investigating data in each cluster against the labels of data segments assigned during data collection stage from subjects' self-reports, we found that there are 3 categories of data corresponding to states of mind including Normal state, Samadhi state, and Intermediate state (meditating but cannot achieve the Samadhi state yet). The prominent feature of the Samadhi state is the appearance of the single narrow peak with high amplitude called the resonant spectral peak. The resonant peak may appear in the LF, or HF ranges. The results apparently show that HRV measures in the Samadhi state and the Non-Samadhi state are remarkably different (see Table 1). The details are elaborated below:

Ordinary quiet sitting

By investigating RR interval time series during ordinary quiet sitting in the time domain, we found the following prominent characteristics. The regularity and the amplitude of signal oscillation are very low. There are several spectral peaks spreading in the VLF and LF ranges. Figure 1 shows a representative of the spectrum of RR interval data during ordinary quiet sitting.

Samadhi State

In the Samadhi state, the regularity and the amplitude of RR interval time series are remarkably high. The spectrum is shifted toward a specific location of frequency to form a single prominent peak called the resonant peak. Figure 2 shows an example of the spectrum of RR interval time series during the Samadhi state. We can notice that there is only one single peak, the high narrow resonant peak in the LF range (LF-resonant peak), while the spectra in the VLF and HF ranges are very low.

Table 1. HRV measures in Normal and Samadhi States.

HRV Measure	Normal State	Samadhi State	
		LF-resonant peak	HF-resonant peak
mHR	70.37	72.95	69.33
AR	0.5271	0.6714	0.6033
VLF (%)	55.21	15.09	19.59
LF (%)	29.89	71.60	25.45
HF (%)	14.89	13.31	54.96
PeakW	5.13	7.21	8.00
PeakF	0.0145	0.0944	0.2067

4. Conclusions

In conclusion, our study revealed that patterns of heart rate variability during concentration meditation and ordinary quiet sitting (normal state) were remarkably different. If the Samadhi state or the state of quiet mind can be achieved, the regularity and the amplitude of oscillation of RR interval data are apparently high. The following features: mean heart rate, autocorrelation coefficient, normalized VLF spectrum, normalized LF spectrum, normalized HF spectrum, width of the highest spectral peak, and frequency of the highest spectral peak can be used as indicators for determining the Samadhi state. The characteristic patterns of power spectrum in the Samadhi state are as follows. Either LF or HF is very high with a narrowed band having high amplitude peak at a certain frequency, while the other bands are very low. Conversely, during ordinarily quiet sitting, the characteristics of the spectral bands are as follows. The VLF is very high, the LF is relatively lower, the HF is quite low, and there are many peaks spreading throughout the VLF and LF bands. Based on the physiological explanations of VLF, LF and HF bands, the Samadhi state may have health benefits relating to baroreflex sensitivity for the ones who can induce the resonant peak in the LF band, and increasing parasympathetic tone for the ones who can induce the resonant peak in the HF band.

Acknowledgements

The authors would like to thank all the subjects and meditation centers for their good collaborations, encouragements, and kind supports.

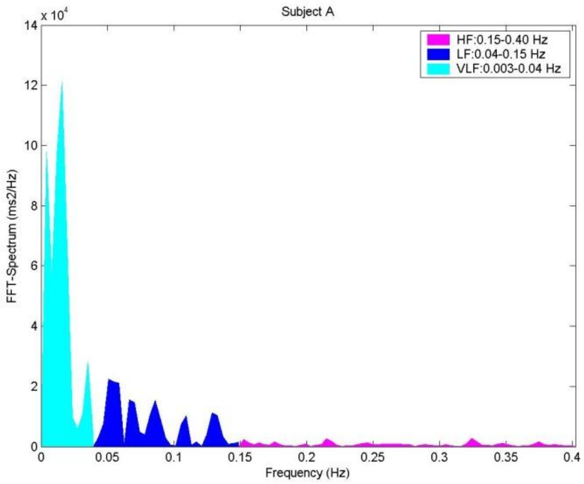

Figure 1. Power spectrum of RR interval data during ordinary quiet sitting (normal state).

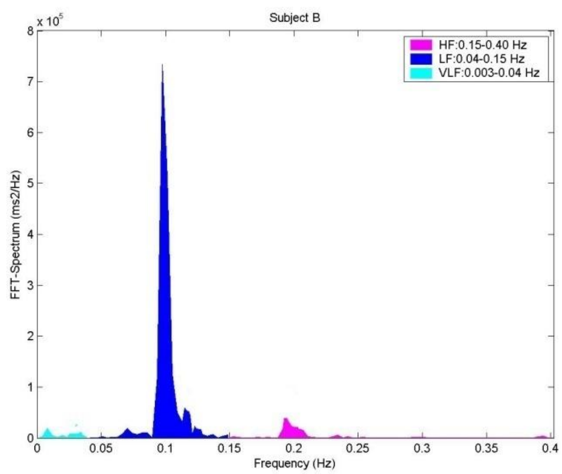

Figure 2. Power spectrum of RR interval data during Samadhi state (the state of quiet mind).

References

[1] Chinwanno W, Phawaphutanon Na Mahasarakam W, Pramaha Chantasilo S, Panyateep S, Kettassa B. Meditation in Tripitaka: Development of Interpretation of Meditation Teaching in Theravada Buddhism in Thailand, (in Thai). Bangkok: Chulalongkorn University Press. 2000.
[2] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. Eur Heart J 1996;17(3):354-381.
[3] McCraty R, Atkinson M, Teller W, Rein G, and Watkins AD. The effects of emotions on short-term power spectrum analysis of heart rate variability. Am J Cardiol 1995; 76(14):1089-1093.
[4] Krittayapong R, Veerakul G, Nademanee K. Heart rate variability in patients with Brugada syndrome in Thailand. Eur Heart J 2003;24:1771-1778.
[5] Peng CK, Henry IC, Mietus JE, Hausdorff JM, Khalsa G, Benson H, Goldberger AL. Heart rate dynamics during three forms of meditation. Int J Cardiol 2004;95(1):19-27.
[6] Phongsuphap S, Pongsupap Y, Chandanamattha P, Lursinsap C. Changes in heart rate variability during concentration meditation. Int. J. Cardiology 2008; 130:481-484.
[7] Lutz A, Greischar LL, Perlman DM, Davidson RJ. BOLD signal in insula is differentially related to cardiac function during compassion meditation in experts vs. novices. NeuroImage 2009;47:1038-1046.
[8] Hoshiyama M, Hoshiyama A. Repeatability value in heart rate associated with experienced Zen meditation. Computing in Cardiology 2010;37:709-712.
[9] Goshvarpour A, Goshvarpour A, Rahati S. Analysis of lagged Poincare plots in heart rate signals during meditation. Digital Signal Processing 2011;21:208-214.
[10] Johnson R, Wichern D. Applied Multivariate Statistical Analysis. Upper Saddle River, New Jersey: Prentice Hall, 1998.
[11] McQueen JB. Some methods of classification and analysis of multivariate observations. Proc. of the 5th Berkeley Symposium on Math Stat and Prob 1967;1:281-297.

Address for correspondence:

Sukanya Phongsuphap
Faculty of Information and Communication Technology
Mahidol University, 999 Phuttamonthon 4 road
Salaya, Nakhon Pathom 73170, Thailand
itsps@mahidol.ac.th