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Analysis of Heart Rate Variability in Meditation Using Normalized Shannon Entropy*

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Abstract: This paper is an attempt in search of human physiology in meditation. Heart rate variability (HRV) signal has been captured and analyzed for this purpose. Two types of data sources have been used, the Physionet[1] and our own data bank, collected by our own instrument. The popular Shannon entropy has been used to measure the complexity of each signal collected from each subject in two different conditions, one in pre-meditative state and the other in meditative state. The Shannon entropy has been normalized by dividing it with the length of the signal because the signals are of different lengths. The results show that the complexity of HRV signal decreases in meditation in compared to its pre-meditative state and that this low complexity is always found in case of advanced meditators but in case of novices the result is mixed. These results satisfy our natural intuition that meditative state has a completely different physiology and that it can be achieved by deep and prolonged meditation only.

Key words: Meditation, Heart Rate Variability (HRV), ECG, Shannon entropy, Complexity

1. Introduction

Meditation is practised from antiquity in almost all human civilizations but only very recently it has drawn some attention to scientific community and as a result, its physiological, psychological and cognitive counterparts are being investigated. Some recent studies[2-6] have been made on different Psycho-physiological aspects of meditation. Peng et.al.[7]first showed that meditation has an effect on heart rate variability. Some other studies have also been made to measure the effect of meditation on heart rate variability[8,9].

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Heart rate variability is gaining increasing popularity to assess different pathological conditions of the heart and now it has been observed that it reflects some mental states also. Non-invasiveness of heart rate variability has made it an attractive tool in the study of human physiological response to different stimuli[10,11]. Heart rate variability (HRV) is the variation of time between consecutive heartbeats. It is a useful tool to know the overall cardiac health and the status of the autonomic nervous system. There are two branches of the autonomic nervous system – the sympathetic and the parasympathetic. The sympathetic branch increases heart rate and the parasympathetic branch decreases it. Thus, at any instant, the observed heart rate variability is an indicator of the dynamic interaction and balance between these two nervous systems. In the resting condition, both the sympathetic and the parasympathetic systems are active with parasympathetic dominance. The balance between them is constantly changing to optimize the effect of all internal and external stimuli[12]. From the previous studies on HRV, it has been revealed that heart rate sequence of all subjects in meditation exhibits 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[13].

Some studies on Zen meditation have also been done[14,15]. In the Zen meditation, it has been observed that, detrended fluctuations analysis (DFA) of HRV is near 0.5 for experienced meditators and 0.78 for beginners[15].

Various complexity measures have been proposed to analyze Heart Rate Variability (HRV) signals. We assume that the reader is familiar with the basic notions of information theory and entropy[16]. In this study we have used an information-theoretic entropy called Shannon entropy to discriminate HRV signal in meditative condition from the non-meditative one. In physical terms, this entropy measure indicates the amount of information encoded in a signal and thus it can be regarded as a measure of complexity in terms of information content. Where the information is much, the signal is more complex and where the information is less, the signal is less complex.

Now we proceed with the formal definition of Shannon entropy. Claude E. Shannon defined a formal measure of entropy, called Shannon entropy[17] which is given by $S = -\sum_{i=1}^{n} p_i log_2 p_i$, where we adopt the convention that

$0 \log 0 = 0$, if necessary.

Here p_i is the probability of occurrence of an event. The Shannon entropy is maximal when all the outcomes are equally likely.

2. Methods

2.1. Data Acquisition

Electrocardiogram signals of the controlled and experimental subjects were recorded in lead-1 configuration employing a laptop based ECG recording system available in the School of BioScience and Engineering, Jadavpur University, India. The recorded data was analyzed using a MATLAB program to detect the R-R intervals for the entire duration of the experiment.

2.2. Subjects and Meditation techniques

Here, two different types of subjects are involved and each group has a different meditation technique. The data of the Chi meditators and the Kundalini Yoga meditators have been obtained from the Physionet and according to the information supplied by the Physionet, the Chi meditators (C1 to C8), 5 women and 3 men are relatively novices in their practice but the four Kundalini Yoga meditators (Y1 to Y4), 2 women and 2 men are advanced meditators. The process of meditation also differs significantly between these two groups. In the process of Chi meditation, it is required to sit quietly and try to visualize the opening and closing of a perfect lotus in the stomach. On the other hand, the Kundalini Yoga meditation consists of sequence of breathing and chanting exercises, performed while seated in a cross-legged posture.

We have also collected HRV signal from three meditators with our own instrument. The subject Yc chanted the 'AUM' mantra for 15 minutes and during the chanting process, the signal was captured, the subject Yd chanted the 'G*ayatri mantra*' mentally, a highly revered mantra in Hinduism taken from the the *Rigveda* for 15 minutes and during the chanting process, the signal was captured. The subject Yp did not follow any specific technique but tried to concentrate on a single thought eliminating the simultaneous flow of multiple thoughts.

2.3. Shannon entropy

The entropy of a random variable is defined in terms of its probability distribution and can be shown to be a good measure of randomness or uncertainty. The Shannon entropy equation provides a way to estimate the average minimum number of bits needed to encode a string of symbols, based on the frequency of the symbols. The seminal work of Claude E. Shannon[17] in 1948, based on papers by Nyquist[18,19] and Hartley[20] rationalized these early efforts into a paper entitled 'A Mathematical Theory of Communication' and initiated the area of research now known as information theory. Shannon showed that a measure of the amount of

information H(p) contained in a series of events with probability $p_1 ... p_N$ should satisfy three natural requirements:

• H should be continuous in the p_i;

• if all the p_i are equally likely, so that $p_i = 1/N$, then H should be a monotone increasing function of N;

• H should be additive.

He then proved that under these constraints H is unique, that is, there is only one H that satisfies these three axioms and the expression of H becomes $H(P) = -K\sum_{i=1}^{N} p_i \log_b p_i$, where K is a positive constant. This expression has been known as the Shannon entropy. The base 'b' of the logarithm is usually taken to be 2, in which case the entropy is measured in 'bits'. The convention 0 log 0 = 0 is assumed in the definition.

In physical terms, entropy is the measure of disorder in a system.

We calculated the Shannon entropy in base 2 for each of the signal and the entropy value was normalized dividing it by the length of the time series. This normalization is necessary because each of the time series is of different length.

3. Results and discussions

The main thing to note is that, in all the advanced meditators (Y1 to Y4), the normalized Shannon entropy reduces in compared to their pre-meditative state but in the case of novices (C1 to C8) no such uniform pattern is found. For example, in the subjects C1, C2, C7 and C8, the normalized Shannon entropy lowers down in meditation but in the subjects C3, C4, C5 and C6, the reverse is true. This tradition continues in our experimental subjects Yc, Yd and Yp also, in case of Yc and Yd the entropy increases but in Yp it decreases because all of them are novices in practice of meditation.

The decrease in Shannon entropy during meditation satisfies our natural intuition because in meditation we try to disconnect ourselves from our environment and try to fix our mind at present moment only removing the thoughts of the past (memory) and the future (imagination). Therefore, number of the external factors that influence our body and mind and consequently our heart, diminish. For this reason, heart needs lesser effort for adaptation with the external factors. Possibly, this phenomenon causes entropy lowering. Also, the consistency of pattern (entropy lowering in meditation) in the advanced meditators, indicate that practising meditation for a prolonged period and development to advanced stage of meditation

effectively help us to keep consistent mental state in meditation which is also quite intuitive.

The normalized Shannon entropy for all the subjects is shown in the following table.

	Pre-meditation	During meditation
Y1	0.00791051	0.00483236
Y2	0.00668253	0.00433348
Y3	0.00717928	0.00589807
Y4	0.0139512	0.00614634
C1	0.00136953	0.00136681
C2	0.00122885	0.00112213
C3	0.00126544	0.00142175
C4	0.00127112	0.00153042
C5	0.00113336	0.00125807
C6	0.00119375	0.00139165
C7	0.00111375	0.000778235
C8	0.00105614	0.000932077
Yc	0.00731731	0.00759108
Yd	0.013876	0.0142064
Yp	0.00642669	0.00564826

4. Conclusion

From this study it is observed that the normalized Shannon entropy of the HRV signal decreases during meditation. If Shannon entropy is interpreted in terms of complexity, then it can be concluded that complexity of HRV signal in meditation becomes lower than the corresponding pre-meditation state. Moreover, this reduction in Shannon entropy occurs in all the advanced meditators but in case of novices, the entropy decreases in some subjects and increases in some subjects. It proves that the advanced

meditators are capable of detaching themselves from the surroundings and remain unaffected from the external stimuli which are manifested here in terms of reduced complexity of the HRV signal. So meditative physiology has some significant difference from the normal one and this difference can be quantitatively measured in terms of normalized Shannon entropy. If anyone wants to judge his or her meditative state, he or she can simply take the HRV signal and use this measure to evaluate it.

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