Effect of music on autonomic nervous system through the study of symbolic dynamics of heart rate variability signals

Anilesh Dey[1], Sanjay Kumar Palit[2], D. K. Bhattacharya[3], D.N. Tibarewala[4].

Abstract- **Effect of music on autonomic nervous system (ANS) from Heart rate variability (HRV) signals of pre-music and on-music states is a very recent area of research. 'n-bit' rank, for some fixed n, of symbolic dynamics has already been applied in connection with HRV signals of Healthy and CHF subjects. But such a study is completely new in connection with effect of music on ANS through HRV signals. The present paper considers 4-bit rank of symbolic dynamics of HRV signals in both pre-music and on-music stages. It shows that the effect of Music is significant in the on-music state. Moreover it also proves that the significant effect of music is not same for all the subjects.**

Keywords-Symbolic dynamics; rank; Q-Q plot; pre-music and on-music HRV data

I. Introduction

Now a days, stress and anxiety have a large negative impact on our society and most of our diseases originate from psycho-somatic disorder. Therefore reduction of stress is necessary for the well-being of our society. Since music has a direct connection with human feeling and mood, it can be used for the reduction of stress of human being. An essential question that may arise at this point is how does music affect human physiological condition and what are the important parameters needed to classify the pattern? During the last two decades, the effect of different types of music to promote relaxation has been studied throughout the globe [7, 10]. The primary focus of those researches was to relate to the subjective responses of the subject, such as pleasure and changes in mood [8] rather than objective physiological responses. However, the results regarding the effect of music were found to be very much conflicting and confusing relating to the exact circumstances and variables that affect the body's response to music, such as the type of music [9] and the subject's involvement in the music [8].

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In some literature, it is found that music decreases the sympathetic nervous system (SNS) and increases parasympathetic nervous system (PNS) activity as measured by heart rate (HR), blood pressure (BP), and heart rate variability (HRV), indicating physiological relaxation [8], while in some other literature it is found that music increases SNS activity and it also increases the HR in subjects who listen to some preferred music after exercise [7]. In fact, it is also found that two other factors – respiratory rhythm [7, 11] and gender [7] affect the human physiological response to music.

HRV [1-4] is a popular non-invasive tool to assess different heart conditions. Due to its non-invasive character HRV has become an attractive tool for its use in the study of human physiological response to different stimuli [5-6]. HRV is the variation of time between two consecutive heartbeats. It is a useful tool to know the overall cardiac health and the status of the autonomic nervous system (ANS). There are two branches of the ANS—the sympathetic and the parasympathetic. The sympathetic branch increases heart rate and the parasympathetic branch decreases it. Thus at any instant, the observed HRV is an indicator of the dynamic interaction and balance between these two nervous systems. In the resting condition, both the sympathetic and 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].

Although the effects of music on mind are mostly realized in brain through Central Nervous system (CNS), music also affects the conditions of heart through the dominance of Para-sympathetic nerves of Autonomic Nervous system (ANS). So it is no less important to study the effect of music through analysis of HRV data extracted from the corresponding ECG signals of the heart in the time domain, when one listens to music.

The study of the symbolic dynamics in HRV signals is not a completely new one. Previously attempts were made with '*n*' bit, *n* = 2, 3, 8 in connection with difference of healthy subjects and CHF subjects [13-15]. Possibly the reason for not considering other values of *n* in (2, 8) is that for such *n* the results were not satisfactory. However in the context of effect of music on HRV signal, we have first considered *n* = 2, 3. But the results are not found to be much encouraging. So we stick to *n* = 4. The results are found to be satisfactory in this case. So we do not consider the case with any n exceeding 4, not to talk of 8.

II. Methods

A. *Acquisition of HRV data*

At first ECG data are collected from different subjects (age between 20 to 30 years male and female.) All subjects are basically students and academicians. The digitized form of ECG data are collected from those subjects and recorded by 'HRV data logger' machine (made by School of BioScience and Engineering, Jadavpur University). All signals are taken at ECE department, Narula Institute of Technology under normal room temperature and least noisy environment. Signals have been collected in two stages. In the first stage ECG are taken at normal condition. Then in the second stage ECG signals are taken when subjects are listening to Rabindra Sangeet .All signals are taken in ten minutes duration. Then recorded signals are processed by MATLABR2010a software using moving window integration of a digital filter and converted into HRV signals.

B. *The Proposed Methodology*

The proposed method is based on the concept of Similarity index and the notion of Q-Q plot. So let us first describe these notions, as follows.

B.1 *Similarity Index*

In human cardiac dynamics sympathetic stimulation and parasympathetic stimulation both exist. Sympathetic stimulation increases and parasympathetic stimulation decreases the heart rate. These interactive force-dynamics may convey some important information via a binary sequence-dynamics. To get the sequence dynamics from a force-dynamics it is useful to apply a mapping which is defined by 1 and 0 corresponding to increase and decrease of the inter-beat intervals of force-dynamics. The resultant binary sequences are enough for the analysis in the form of a symbolic sequence.

Suppose the inter-beat interval time sequence is given by $\{x_1, x_2, x_3, ..., x_n\}$, where x_i represents the ith inter-beat interval. This time sequence is converted into symbolic dynamics by a mapping $f: \{x_1, x_2, x_3, ..., x_n\} \rightarrow B$, which is defined by

$$f(x_r) = 1 \text{, if } x_r \leq x_{r+1}$$
$$= 0, \text{ if } x_r > x_{r+1},$$
$$r = 1.2.,,.n$$

Thus by the mapping f the sequence $\{x_1, x_2, x_3, ..., x_n\}$ of length n becomes the binary sequence *B* of length (*n*-1).

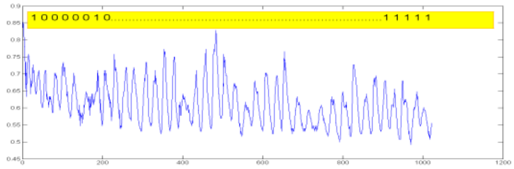


Figure 1. Binary series for a heartbeat time series obtained under the mapping *f*.

Let w_k denote the *k* bits word that represents a unique pattern in the binary sequence B, Obviously there exists 2^k such words. Let w_k^i denote the i^{th} *k* bits word. Corresponding to each w_k^i, the rank of w_k^i, denoted by $R(w_k^i)$ is defined as

$R(w_k^i) =$ number of w_k^i that appears in the binary sequence *B*, $i = 1, 2, 3, ..., 2^k$.

It is claimed in [16] that the occurrence of these *k* bit words may reflect the underlying dynamics of the original time sequence.

B.2 *Q-Q plot (Quantile-Quantile plot)*

In statistics, a Q-Q plot [15] ("Q" stands for quantile) is a probability plot, which is a graphical method for comparing two probability distributions by plotting their quantiles against each other. Q-Q plot is a plot of the quantiles of two distributions against each other, or a plot based on estimates of the quantiles. The pattern of points in the plot is used to compare the two distributions. The points plotted in a Q-Q plot are always non-decreasing when viewed from left to right. If the two distributions under comparison are identical, the Q-Q plot follows the line y = x. If the two distributions agree after transforming the values linearly in one of the distributions, then also the Q-Q plot follows some line, but this line is not necessarily the line y = x.

B.3 *Our methodology*

First we consider only 2 bit words, starting from 00 to 11; these are denoted by w_2^i, $i = 1, 2, 3, 4$.

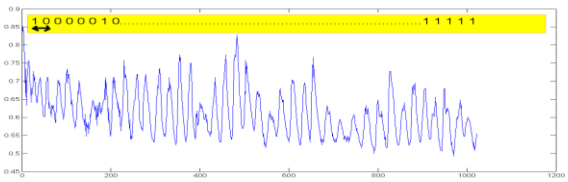
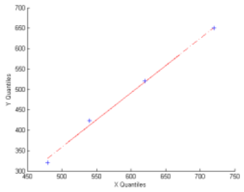


Figure 2. Schematic illustration of the mapping procedure for 2-bit words from a heartbeat time sequence.

This collection of 2 bit words over the whole time sequence is obtained by shifting one data point at a time. Now the rank is calculated for each such word. This actually produces a sequence of rank values for the binary sequence of the HRV signal under consideration. Finally the probability distributions of the rank values for every pair of HRV signals (i.e. HRV signals of both pre-music and on-music states) are compared by Q – Q plot.



'a1pre Vs. a1music'

Figure 3. Q-Q plots of the rank value sequences obtained for pre-Music and on –music HRV considering 2 bit word as rank

It is evident from fig.3 that all the points are on the dotted straight line, parallel to y = x. So the distribution of the rank values is unable to distinguish pre-music and on-music HRV signals. But for the sake of convenience, only one of them is presented in the above figure. This confirms that no dissimilarity in the HRV dynamics is present for subjects of pre-music and on-music states.

Next we consider only the 3 bit words, starting from 000 to 111; these are denoted by w_3^i , $i = 1, 2, 3, ...8$.

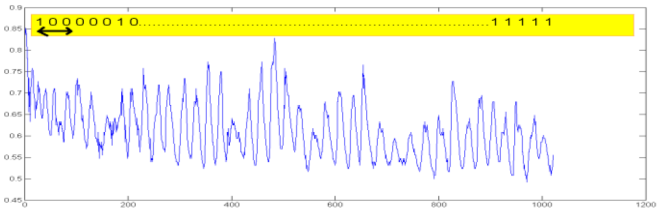
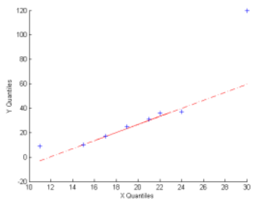


Figure 3. Schematic illustration of the mapping procedure for 3-bit words from a heartbeat time sequence.

Here we apply the same procedure as above and get figure 4.



'a1pre Vs. a1music'

Figure 4. Q-Q plots of the rank value sequences obtained for pre- Music and on –music HRV considering 3 bit word as rank

From fig.4 it is found that all the points are on the dotted straight line, parallel to y = x, i.e., the distribution of the rank values is still unable to distinguish pre-music and on-music HRV signals.

So we consider 4 bit words, starting from 0000 to 1111; these are denoted by w_4^i , $i = 1, 2, 3, ...,16$. This collection of 4 bit words over the whole time sequence is obtained by shifting one data point at a time. Now the rank is calculated for each such word. This actually produces a sequence of rank values for the binary sequence of the HRV signal under consideration.

Finally the probability distributions of the rank values for every pair of HRV signals (i.e. HRV signals of both pre-music and on-music states) are compared by Q – Q plot.

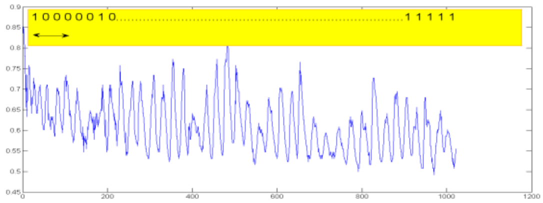
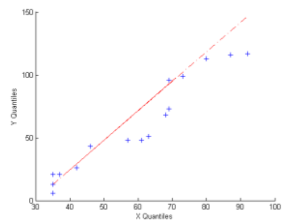


Figure 5. Schematic illustration of the mapping procedure for 4-bit words from a heartbeat time sequence.

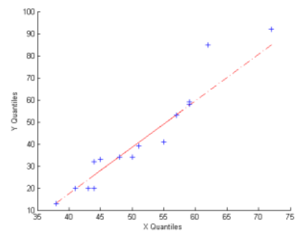
III. Result and Discussion

Q – Q Plot of the rank value sequence for Pre-meditative HRV

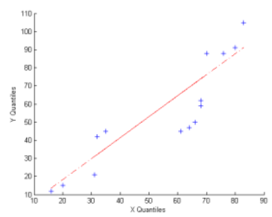
As an illustration few Q-Q plots obtained for the rank value sequence of the HRV signals for pre-music and on-music states are presented in fig.6



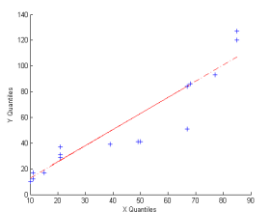
a1pre Vs a1 music



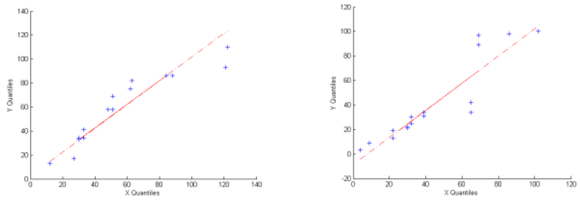
a2pre Vs a2music



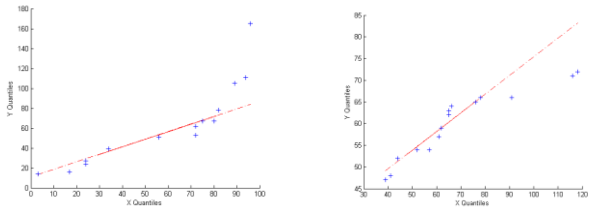
. a3preVs a3 music



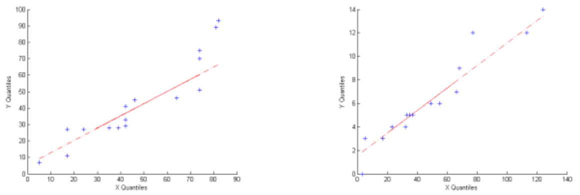
a4preVs a4music



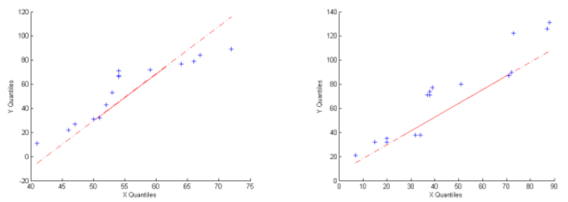
a5pre Vs a5 music a6preVs a6music



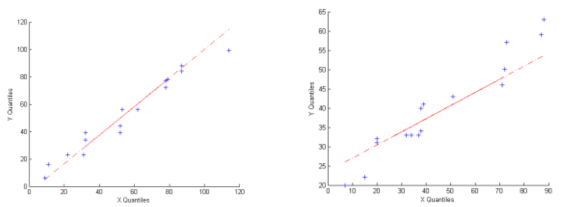
a7pre Vs a7 music a8preVs a8music



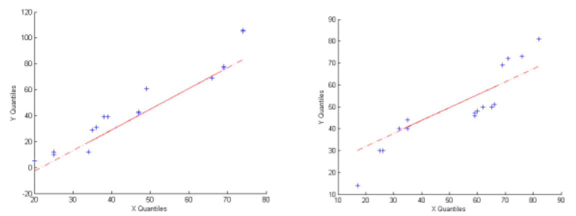
a9pre Vs. a9music a10pre Vs. a10music



a11pre Vs. a11music a12pre Vs. a12music



a13pre Vs. a13music a14pre Vs. a14music



a15pre Vs. a15music a16pre Vs. a16music

Figure 6. Q-Q plots of the rank value sequences for every pair of pre-music and on-music HRV.

It is evident from fig.6 that most of the points are far away from the dotted straight line, parallel to y = x, i.e., the distribution of the rank values of pre-music HRV is different from that of on-music HRV.

Conclusions

Rank value sequences of the HRV signals for pre-music and on-music states when shown on Q – Q plot exhibit two types of significant results: (1) On-music states always show deviations from the line y = x, (2) The deviations are not same for all the subjects. Therefore the conclusion is that music has a significant effect on ANS and further the effect differs from person to person.

However, it may be noted that the present study is carried out only on a smaller sample size of data and so further investigation is required on a larger sample size of data size to substantiate the results of the present work.

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