



A Signal Processing Approach to the Reduction of Stress with the application of Music

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ABSTRACT

In the modern society, the negative impacts of stress and anxiety have been very apparent. So reduction of stress and its after-effects is a very important facet of studies on the human mind. It has been widely seen that music has a mitigating impact on the effects of stress and anxiety. This article deals with the issue of reduction of stress, through a signal processing viewpoint. As a method of studying the effects of stress and anxiety, we have taken the HRV (heart rate variability) signals obtained from the subjects in two stages: first, when the subjects are solving puzzles, and second, in a post-music state. These signals have been analysed using 2-D Poincaré plots which have shown satisfactory results from a mathematical, as well as human physiological point of view.

General Terms

Signal Processing, Music Application

Keywords

2-D Poincaré plots, HRV Signal, Stress Condition, Post-Music Condition.

1. INTRODUCTION

The very existence of human life is maintained by a dynamic equilibrium, which stabilizes the internal conditions of a person. This condition is termed as homeostasis. But this condition is constantly under threat from external aggressors, termed stressors [1], which tend to disrupt the stability. One such bane of today's competitive world is stress, and stress related problems are becoming common among people today.

Stress is an organism's response to a stimulus that puts demands on the human body that it cannot handle at that moment i.e. a stressor. There are numerous emotional and physical disorders that have been linked to stress including depression, anxiety, heart attacks, stroke, hypertension, etc. which bring on immune system disturbances [3][4][5][6][7]. In fact, stress plays an exacerbating role in the body for it does not leave any part of it unaffected. This list will undoubtedly grow as the extensive ramifications of stress are increasingly being appreciated. In this article, we study the effect on the human body, especially on the heart, by the application of stress.

We have seen that music is one of the more popular ways of stress management. The aim of our study is to observe the effects of music on reduction of stress in individuals. This is done by exposing the individuals to problems of varying difficulties and then, making them listen to music, as a

method of relaxation. As a parameter for measurement of the physiological condition we choose the heart rate variability (HRV) signals taken from subjects solving some puzzles and then, listening to a particular type of music (Rabindra Sangeet, in this case). The puzzles for the subjects have an increasing order of difficulty: easy to hard, then harder to hardest. Each of these puzzles have a time span of 10 minutes, and the measurements are taken in the final 10 minutes, when the subjects are solving the hardest puzzles. The subjects are then allowed to listen to the music for a fixed time span of 15 minutes. We take measurements of HRV signals with our own ECG machine after each task to obtain readings after application of stress through the puzzles, and then relaxation through music.

The subsequent relaxation in the individuals has been brought about by making them listen to Rabindra Sangeet, composed by the famous poet and Nobel laureate, Rabindranath Tagore. This form of music is filled with expressions of romanticism, and is very much popular in India and Bangladesh. For our study, we have used the songs of the Love chapter, one of the six chapters, of Tagore's collection of compositions Gitabitan ("Garden of Songs").

For data analysis, the Poincaré plot in spherical coordinate is used. Each of the plots obtained appear to form a single cluster resembling an ellipse having some outliers. We observe from these plots that the cluster varies uniquely in under stress conditions and under relaxed conditions, and these variations are different for different subjects. This shows that under different conditions, the human physiology, especially that of the heart, has some definite effects. This study can be used to deal with problems pertaining to human stress and relaxation conditions.

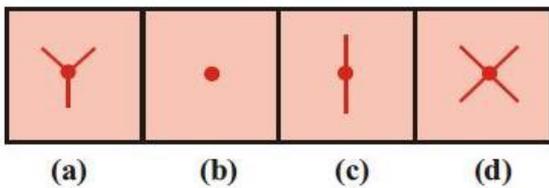
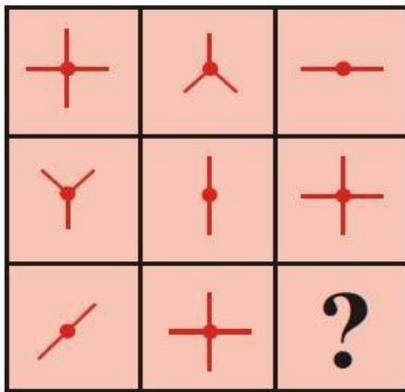
Previous studies (Das, M. et al 2015) [8] have focused on pre-music and on-music state, assuming a calm environment prevalent around the test subjects. In this paper, our aim is to study the HRV observations in a similar environment, obtained from a subject under stress, and then, the observations obtained in post-music state, where the heart rate is supposed to decrease.

2. METHODOLOGY

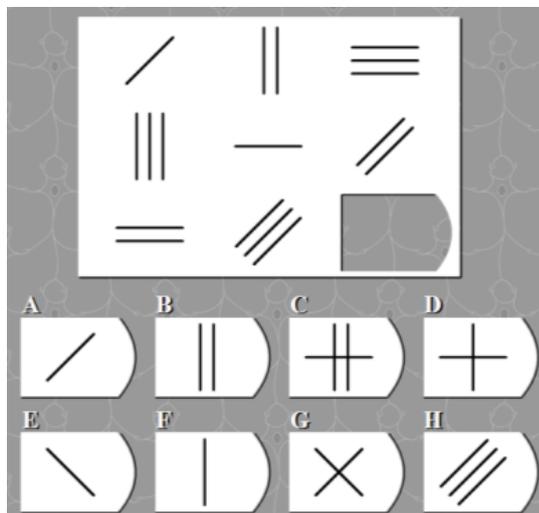
2.1 Experimental Procedure And Acquisition Of Signals

This experiment consisted of four different types of cognition based experiments. These experiments were conducted on ten healthy volunteer individuals, of which four are male and six are female, who are students of the age group 18-22 years. Each of the experiments are described below:

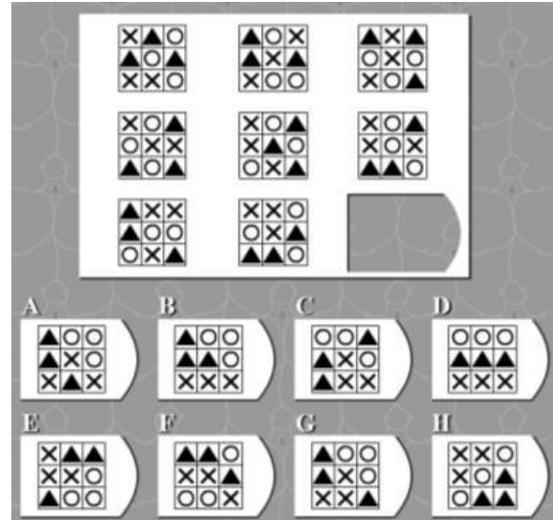
The first type of experiments were conducted by making the individual solve puzzles where the difficulty level was very low. These puzzles were intended to familiarize the individuals with the process of experimentation. They had 10 minutes each to solve these questions, and the difficulty level of these questions gave the subjects ample time to solve them easily. A specimen of the type of questions expected in this set of experiment is shown [9]:



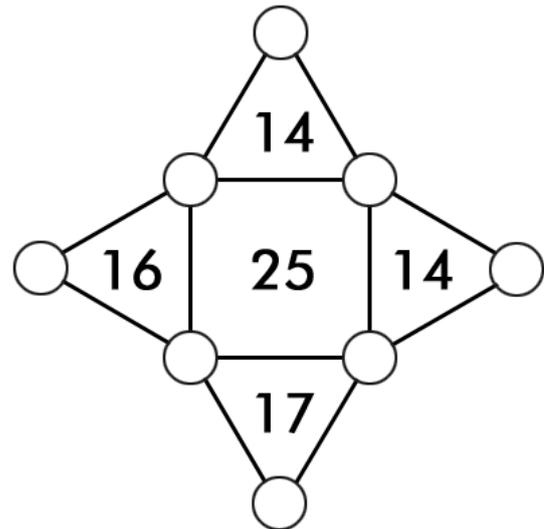
Then the second type of experiment was conducted using puzzles which were harder than the previous level. The subjects had 10 minutes each to solve these puzzles. A specimen of the questions in this section is given below [10]:



The third type of experiments had puzzles whose level of difficulty increased. The time limit for these puzzles was the same. This made the idea of increasing difficulty apparent to the individuals. An example of questions for this level is shown [11]:



The fourth and last type of experiment had the hardest puzzles of the lot. To increase the level of stress on the individuals, the time limit was kept the same i.e. 10 minutes. The measurements for HRV were taken during the time the subjects were solving these puzzles, and subsequent readings were based on these measurements. Questions for this type are of the following type, where the subjects had to fill the circles with numbers from 1 to 8, without any repetition, such that the sum of the numbers in any three circles is equal to the number surrounded by them [12]:



Once these tasks had completed, the subjects were allowed to rest for 15 minutes while the music (Rabindra Sangeet, in this case) was played to them. Since the motive of our study is to know the effect of music on the HRV signals, the measurements were taken subsequently, after the listening period had elapsed.

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, India). Signals have been collected in two stages. In the first stage, ECG's are taken when people are involved in cognitive task of the fourth type. Then, in the second stage, ECG signals are taken after the people have listened to the music. All signals are taken under normal room temperature and least noisy environment. All signals are taken in ten minutes duration. Then recorded signals are processed by MATLAB R2014b software using moving window integration of a digital filter and converted into HRV signals.

2.2 Standard Poincaré Plot Descriptors [2]

The Poincaré plot obtained from each measurement is in the form of a group of clustered points that take the shape of an ellipse. Two basic parameters that describe this plot are termed as SD1 and SD2. These terms are called “Poincaré Plot Descriptors” [3][4].

The definitions of SD1 and SD2 are given in terms of variance of transformed and projected (RR_i, RR_{i+1}) pairs. Hence the geometric interpretation of the second moment with respect to a straight line gives equivalent definition of this language, which will be used later. Mathematically, the values for RR, x and y vectors are defined as follows:

$$RR \equiv RR_1, RR_2, \dots, RR_n, RR_{n+1} \quad (1)$$

$$X \equiv (x_1, x_2, \dots, x_n) \equiv (RR_1, RR_2, \dots, RR_n) \quad (2)$$

$$Y \equiv (y_1, y_2, \dots, y_n) \equiv (RR_1, RR_2, \dots, RR_n) \quad (3)$$

Here,

$RR_i = i^{\text{th}}$ RR interval

$N =$ number of points in the Poincaré Plot (which is one less than the length of the RR time series).

Using these formulae, the Poincaré plot can be defined by the ordered pairs (x_i, y_i) . The centroid, or the first moment (x_c, y_c) of a distribution of n points (x, y) is defined as:

$$\sum_{i=1}^n X_c = \sum_{i=1}^n X_i \quad (4)$$

$$\sum_{i=1}^n Y_c = \sum_{i=1}^n Y_i \quad (5)$$

In our case, the centroid of the Poincaré Plot is:

$$\bar{x}_c = \bar{x}_i \quad (6)$$

$$\bar{y}_c = \bar{y}_i \quad (7)$$

Here, the bar quantities stand for their mean values.

Now,

$$l_1 : y - y_c = \tan\left(\frac{\pi}{4}\right)(x - x_c) \quad (8)$$

$$l_2 : y - y_c = \tan\left(\frac{3\pi}{4}\right)(x - x_c) \quad (9)$$

Now, the distance of the i^{th} Poincaré Plot point from l_1 and

l_2 is d_i^1 and d_i^2 , respectively, given by:

$$d_i^1 = \frac{|(x_i - x_c) - (y_i - y_c)|}{\sqrt{2}} \quad (10)$$

$$d_i^2 = \frac{|(x_i - x_c) + (y_i - y_c)|}{\sqrt{2}} \quad (11)$$

Hence, we obtain the following formulae for $SD1_c$ and $SD2_c$:

$$SD1_c^2 = \frac{1}{n} \sum_{i=1}^n (d_i^1)^2 \quad (12)$$

$$SD2_c^2 = \frac{1}{n} \sum_{i=1}^n (d_i^2)^2 \quad (13)$$

Thus we obtain an identity line in the Poincaré Plot, which can be interpreted in a simple manner as: the points on this line represent consecutive equal RR intervals, the points above it correspond to increase in heart rate and the points below it correspond to decrease in heart rate.

2.3 Second Moment of the Poincaré Plot with respect to the Line of Identity

This section deals with the breakage of $SD1^2$ which is obtained with the help of the properties of the line of identity, and contributed to by the points above and below it i.e. the extended and shortened RR intervals.

The mathematical definition of $SD1^2$ is given as:

$$SD1_i^2 \equiv \frac{1}{n} \sum_{i=1}^n D_i^2 \quad (14)$$

Here, the perpendicular distance of each Poincaré Plot to the line of identity, D_i can be expressed as:

$$D_i = \left| \begin{pmatrix} x_i \\ y_i \end{pmatrix} \times \frac{\sqrt{2}}{2} \begin{pmatrix} 1 \\ 1 \end{pmatrix} \right| = \frac{|x_i - y_i|}{\sqrt{2}} \quad (15)$$

From the geometry of mechanics [2], it is known that the line through a centroid minimizes the second moment in the considered direction. This gives us:

$$SD1_i^2 \geq SD1_c^2 \quad (16)$$

Using Steiner's Theorem,

$$SD1_i^2 = D_c^2 + SD1_c^2 \quad (17)$$

Where D_c is the distance from the centroid to the line of identity, and it can be calculated as:

$$D_c = \frac{|x_c - y_c|}{\sqrt{2}} = \frac{1}{n} \frac{|x_1 - y_n|}{\sqrt{2}} = \frac{1}{n} \frac{|RR_1 - RR_{n+1}|}{\sqrt{2}} \quad (18)$$

Here, n is the number of points in the plot. So, the difference between $SD1_i^2$ and $SD1_c^2$ is given as:

$$\Delta \equiv SD1_i^2 - SD1_c^2 = \frac{1}{n^2} \frac{(RR_1 - RR_{n+1})^2}{2} \quad (19)$$

So, finally we get,

$$\lim_{n \rightarrow 0} \Delta = 0 \quad (20)$$

The numerical difference between $SD1_I^2$ and $SD1_C^2$ is very small, so we use the definition of $SD1_I^2$ as the basis for defining SD1.

2.4 Measures of Asymmetry of the Poincaré Plot

We know that, the second moment around the line of identity is:

$$SD1_I^2 \equiv \frac{1}{n} \sum_{i=1}^n D_i^2 \quad (21)$$

If we separately take the points above the line of identity from the points below it, the above equation can be rewritten as:

$$SD1_I^2 = \frac{1}{n} \left(\sum_{i=1}^{n_U} (D_U^i)^2 + \sum_{i=1}^{n_D} (D_D^i)^2 + \sum_{i=1}^{n_O} (D_O^i)^2 \right) \quad (22)$$

Or

$$SD1_I^2 = \frac{1}{n} \left(\sum_{i=1}^{n_U} (D_U^i)^2 + \sum_{i=1}^{n_D} (D_D^i)^2 \right) \quad (23)$$

Where,

D_U^i, D_D^i, D_O^i : Distance of the i^{th} point above, below and on the line of identity (U, D and O stand up for Up, Down and On respectively)

n_U, n_D, n_O : Number of points above, below and on the line of identity

Hence,

$$D_O^i \equiv 0, \text{ for all } i \text{ and } n_U + n_D + n_O = n \quad (24)$$

Therefore,

$$SD1_I^2 = SD1_{UP}^2 + SD1_{DOWN}^2 \quad (25)$$

Where,

$$SD1_{UP}^2 = \frac{1}{n} \left(\sum_{i=1}^{n_U} (D_U^i)^2 \right) \quad (26)$$

$$SD1_{DOWN}^2 = \frac{1}{n} \left(\sum_{i=1}^{n_D} (D_D^i)^2 \right) \quad (27)$$

Thus, the second moment around the identity line has been partitioned into two parts, corresponding to accelerations ($SD1_{UP}$) and deceleration ($SD1_{DOWN}$) of the heart rate.

3. RESULTS AND DISCUSSION

Examples of the Poincaré Plots obtained for under stress condition and post music condition are shown here:

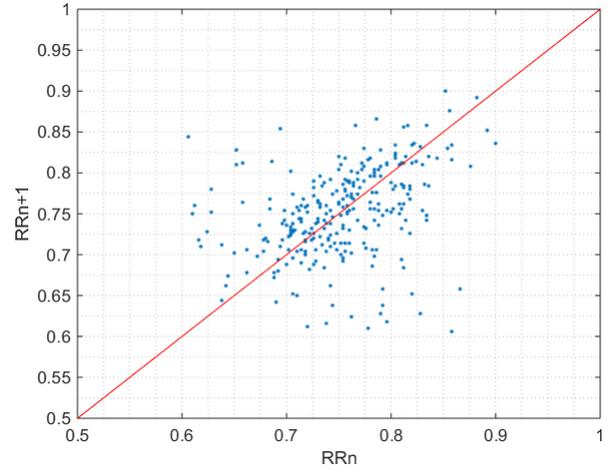


Figure 1: Plot for under stress condition

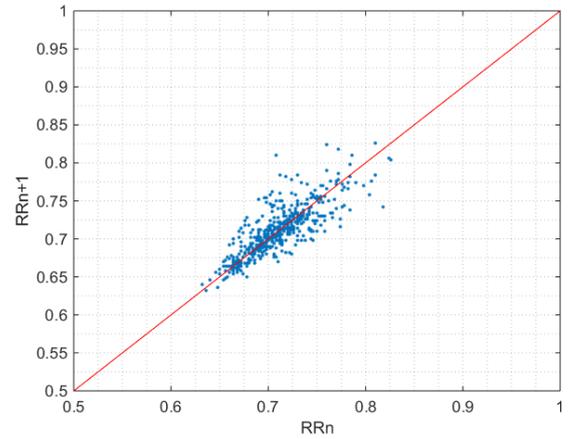


Figure 2: Plot for post music condition

Table 1. The table for measurements obtained under stress conditions

Stress Condition State		
Subject	SD1_Up	SD1_Down
1	0.019019994	0.016596823
2	0.015329645	0.014956571
3	0.027485297	0.024902387
4	0.010852618	0.009628024
5	0.03271455	0.029503337
6	0.033524367	0.031408313
7	0.032296309	0.030662782
8	0.02915837	0.026909434
9	0.043574464	0.04164637



10	0.012203125	0.010704265
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Table 2. The table for measurements obtained under post music conditions

Post Music State		
Subject	SD1_Up	SD1_Down
1	0.02118101	0.023456611
2	0.03473787	0.042554767
3	0.00921319	0.01050546
4	0.02378246	0.025730859
5	0.04641214	0.049356438
6	0.01768975	0.019456324
7	0.02179888	0.024178804
8	0.02458163	0.027573347
9	0.04918978	0.053275843
10	0.04853213	0.05299075

From the Table 1, we observed that $SD1_{UP} > SD1_{DOWN}$ for the cases seen here, when under stress. This gives us a larger upper part of the Poincaré Plot, which represents acceleration of the heart rate. At the same time, in the 10 recordings of Table 2, we see the opposite results i.e. here we have $SD1_{UP} < SD1_{DOWN}$, which gives a larger lower part of the Poincaré Plot, which represents deceleration of the heart rate. So, at the end, it has been seen that in the post-music state, the heart rate decreases which gives the positive impact in this context.

4. CONCLUSION

This article exhibits specific changes in the HRV signals of the subjects in under stress condition and post-music condition. And we have seen that the data obtained from the results exhibit results that conform to our study. From this we can infer that music has a calming effect on an individual’s mind. In this article, the effects on the normal healthy subjects have been obtained using 2-D Poincaré plots. And we have seen that the value of the definitive parameter i.e. $SD1_{DOWN}$, increases for all subjects, on exposure to Rabindra Sangeet, which clearly emphasizes the positive influence that Rabindra Sangeet has on eliminating stress from the human mind. Present studies have been done by using small samples of data. But, as a scope for future, studies can be conducted on larger samples of data to obtain further results.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

- [1] Varvogli, L., Darviri, C., “Stress Management Techniques: evidence-based procedures that reduce stress and promote health”, Health Science Journal, Vol. 5, Issue 2, 2011
- [2] Piskorski, J., Guzik, P., “Geometry of the Poincaré plot of RR intervals and its asymmetry in healthy adults”, IOP Publications, 2007
- [3] Anilesh Dey, Sanjay Kumar Palit, Sayan Mukherjee, D. K. Bhattacharya, D.N. Tibarewala, “Are Meditative states distinguishable from the pre-meditative ones? A new alternative study” IEEE International Conference on Advances in Engineering, Science and Management (ICAESM), 2012, Page(s) 456 – 461, Print ISBN:978-1-4673-0213-5
- [4] Anilesh Dey, Sanjay Kumar Palit, Sayan Mukherjee, D. K. Bhattacharya, D.N. Tibarewala, “A new technique for the classification of pre-meditative and meditative states”, IEEE International Conference, “ICCIA-2011”, Print ISBN:978-1-4577-1915-8
- [5] Anilesh Dey, Sanjay Kumar Palit, D. K. Bhattacharya, D.N. Tibarewala, Debraj Das, “Study the effect of music on Central nervous system through long term analysis of EEG signal in time domain”. International Journal of Engineering Science and Emerging Technologies Volume: 5, Number: 1 (2013), pages 59-67, ISSN: 2231-6604
- [6] Anilesh Dey, Sanjay Kumar Palit, Sayan Mukherjee, D. K. Bhattacharya, D.N. Tibarewala, “A new technique for the classification of pre-meditative and meditative states”, IEEE International Conference, “ICCIA-2011”, Print ISBN:978-1-4577-1915-8
- [7] Anilesh Dey, Sanjay Kumar Palit, D. K. Bhattacharya, D.N. Tibarewala, Debraj Das, “Study the effect of music on Central nervous system through long term analysis of EEG signal in time domain”. International Journal of Engineering Science and Emerging Technologies Volume: 5, Number: 1(2013), pages 59-67, ISSN: 2231-6604.
- [8] Madhuparna Das, Tuhin Jana, Parna Dutta, Ria Banerjee, Anilesh Dey, D. K. Bhattacharya, M. R. Kanjilal, “Study the Effect of Music on HRV Signal using 3D Poincare Plot in Spherical Co-ordinates – A Signal Processing Approach”, International Conference on Communication and Signal Processing, 2015, ISBN: 978-1-4799-8080-2
- [9] “Fill in the Matrix – Level 1”, <http://www.smart-kit.com/s3595/fill-in-the-matrix/>, accessed on 20/11/2015 at 2:41 p.m.
- [10] “IQtest.dk – Question 12”, <http://iqtest.dk/main.swf>, accessed on 20/11/2015 at 2:47 p.m.
- [11] “IQtest.dk – Question 39”, <http://iqtest.dk/main.swf>, accessed on 20/11/2015 at 3:01 p.m.
- [12] “Brain Bashers – Brain Teasers and Puzzles”, <http://www.brainbashers.com/showpuzzles.asp?page=1&formpost=Y&d2=Y>, accessed on 20/11/2015 t 3:47 p.m.