Stress and Heart Rate Variability

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Abstract. Do people get accustomed to stress? Do people react differently to a stressful environment when they have experienced the situation earlier? This paper reports research to determine whether the above is a myth. It reports the measurement of heart rate variability (HRV) of people when subjected to controlled stress conditions and these conditions are repeated over different days. The results indicate that while there is a large variability between different participants, there is a consistent reduction in the heart rate variability from the first experience of the stress condition to the subsequent applications of similar stress conditions.

1 Introduction

Autonomic responses in psychologically challenging situation are a major area of psychophysiological study and research. Psychophysiology is defined as the study of relations between psychological manipulations and resulting physiological responses, and has developed over the years to promote better understanding between psychological and physiological processes [1]. There are number of anecdotal evidences suggesting the change in heart rate (HR) with stress of the person. Patients suffering from cardiac conditions are often asked to reduce their anxiety and psychological stress. Changes in cardiac activity had been observed by early scientists related to psychological phenomena [1]. In the recent past, researchers have used heart rate and its variability as a measure of mental load [2]. Variability of heart rate has also been used for 'lie detector' applications.

While the phenomena of change in heart rate with stress of people seems to be widely accepted, Indian society has known the use of techniques such as yoga and meditation to control the cardiac activity for thousands of years. In our modern technology driven society, biofeedback is being considered for helping individuals have some control on their cardiac activity. In each of these, the individual makes a conscious effort and often undertakes training to develop a control over their heart rate.

Social health scientists believe that this stress causes increased cardiac stress and results in long term damage to the body of the individuals living under these conditions

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[3], [4], [5]. But in our modern society, some of us are regularly exposed to stress and anecdotal evidence suggests that we get accustomed to this stress. It is then arguable that people who are used to living under stress may be developing immunity from the stress at their physiological levels. It has been argued that stressful environment becomes less challenging to an individual who is used to working in such an environment and such an individual will have little change in their heart rate when under stress. Thus, it maybe suggested that the bodies of people who work in stressful and challenging professions would be able to cope with the stress easily with little changes to their cardiac activity compared with other people. This paper reports experimental research to test the above commonly held beliefs. The paper reports tests conducted on different days to determine the correlation between changes to heart rate as the participants became accustomed to the controlled stress conditions. For this purpose, controlled experiments were conducted where electrocardiogram of the participants was recorded and correlated with the controlled stress conditions.

1.1 Electrocardiogram

Electrocardiogram (ECG) is the electrical potentials of the heart and generally recorded non-invasively from the surface of the body. The first known equipment to record ECG was invented by Williem Einthoven. The origin of the electrical activity measured by ECG is in the cardiac muscle fibres. ECG can be divided in phases of depolarization and repolarization of different sections of the heart. The most significant section of ECG is the QRS complex, the peak of which is 'R' wave. QRS corresponds to the contraction of the left ventricle.

ECG is a repetitive signal and corresponds with the beating of the heart. The rate of repetition of ECG, measured using QRS peak, corresponds with the heart rate. The HR of different people is not comparable due to differences such as body size, age and genetics. Heart rate of an individual varies with number of factors including stress and physical exercise. Due to these reasons, there is a very large inter and intra subject variability and hence heart rate and ECG repetition are not useful for comparison. But variation of heart rate is a more reliable measure of changes to the cardiac activities [6].

1.2 Heart Rate Variability

The heart rate variability (HRV) has been recognized as a non-invasive means to assess the state of autonomic nervous system [7]. The autonomic nervous system (involuntary nervous system) consists of two components; the Sympathetic and the Para-sympathetic branch. Increased activity of sympathetic branch causes an increase in the heart rate while increase in Para-sympathetic branch causes the slowing of heart rate. When the individual is under stress, the sympathetic activity is more profound than the Para-sympathetic activity causing an imbalance in the autonomous nervous system (ANS) and hence the HR of the person increases [8]. HRV analysis is a measure of the variability in heart rate; specifically, variability in intervals between successive R waves - "RR intervals". This is also called as Interbeat Interval (IBI) and is defined as time in milliseconds between two normal R to R waves of an ECG. The variations of the heart rate are affected by a diverse number of factors such as the metabolic activity (related to physical activity) and emotional activity. The change in heart rate affects the overall well-being of the person including their physical abilities and mental and emotional capabilities. Drastic change in HR is known to affect the individual's capability to take decisions, solve problems, and the overall perception of the events and environment [9]. The relationship between mental stress and HRV is a very active area of research for human-machine interface. Number of studies have been reported that have analyzed HRV with mental stress to identify the impact of various factors on our wellbeing such as during physical work [10], with controlled breathing [11], with and without vocalization [4], [12], effect of individual differences on stress responsivity [13], with electrical stimuli [1]. The studies suggest that HRV is an effective, objective and non-intrusive measure for mental stress evaluation.

This paper reports the study conducted to determine whether repeated exposure to stress reduces the impact of emotional and psychological stress on the HRV of the individuals. For this study, mental tasks have been used as the laboratory emotional and psychological stressors. Based on other reported studies, tasks requiring mental arithmetic (MA) have been used (e.g. [10]; [11]; [12]). The mental tasks that were applied as stimuli ranged from simple to difficult mathematical operations, and memory tests (e.g. English sentence reordering etc.).

2 Methodologies

The aim of this research was to identify the changes in HR due to emotional and psychological stress. Towards this aim, controlled experiments were conducted where the HR was recorded when the participant were made to undertake the mental tasks, with all other conditions kept unchanged. These experiments were repeated for three days.

Participants performed five minute simple mental tasks on three consecutive days. For each day, participants were asked to solve a series of mental tasks that are detailed below.

2.1 Mental Tasks

The participants were given a number of mental tasks on each day, design of these tasks adopted from [1]. These tasks consisted of three set of tasks; word memory, numeric and tasks requiring planning. The set of these tasks were repeated three times (one participant did this four times). Between each stimulus, the participants were encouraged to relax for about one minute. In accordance with [12], the participants were asked to vocalize their responses to the mental tasks. The mental tasks stimulus to which the participants were subjected is described below:

2.2 Day 1

The first mental task that was given to the participants was a 'memory task'. The participants were given eight randomly selected commonly used mid-size English words and were asked to read these aloud (excluding 3 punctuation marks). Ten seconds after this was completed, they were asked to repeat the eight words in the same order.

The second mental task for the day was a quantitative problem involving one step, single digit multiplication. This required the participant to calculate the hourly speed of the car, given the distance the car travelled for 15 minutes.

The third task required the participant to unscramble a jumbled word. The word was selected randomly, it was five or six characters long, and of common usage.

2.3 Day 2

The tasks on the second day were similar to that of the first day, but were in a different order and of greater complexity. The first task was a numeric task, similar to the second task of day one, where the participant was given a simple single digit multiplication task.

The second task for the second day was also a numeric task where the participant was asked to divide a randomly generated five digit number by ’7’ to the second decimal places orally. The third task was a two digit oral multiplication. The fourth task was a memory test, similar to task one on day one.

2.4 Day 3

The tasks and the order of the tasks used on the earlier two days were randomly selected for the third day. The actual words and numbers were changed for each experiment.

3 Participants

Sixteen (male and female) University students volunteered to participate in the study. All participants were in good health with no history of cardiovascular disease and were not under any medications that may affect their cardiovascular functions. All participants were advised to abstain from caffeine, alcohol and nicotine for at least 2 hours before testing.

4 Apparatus

Electrocardiogram (ECG) were measured using a BIOPAC ECG100C amplifier. The ECG was measured using Ag-AgCl disposable sensors with a high conductivity wet gel. AcqKnowledge (Biopac) software was used to record the ECG. The sampling rate was 200 samples/sec. The analysis was done offline using MATLAB.

5 Procedure

The experiments were conducted in accordance with the University Human Ethics Committee approval. The participants were informed that they were free to stop the experiment when they so wished without giving any reason. The participants were made aware of the details of the experimental procedure, the overall aim of the project and were made familiar with the laboratory and the apparatus. The participants were provided with the plain language statement of the experiments. They were included in the experiments after they signed the consent form. The room was air-conditioned with temperature maintained between 20^{o}C and 22^{o}C throughout all the experiments.

At the start of each session, the participants washed their hands using warm water and soap free cleanser; they sat down in a comfortable chair. Disposable Ag/AgCl electrodes were attached in the 3-lead configuration. The location of the electrodes was marked to ensure repeatability over the different experiments. The apparatus was calibrated to ensure reproducibility.

The participant was asked to relax for five minutes after the electrodes were attached to them. At this end of this period, the participant continued to relax for another five minutes, and during this time their ECG was recorded. This ECG corresponded to the relaxed state and HR during this period was taken as the base level for all other comparisons. At the completion of this period, the participant was given a series of mental tasks while their ECG was being continuously recorded. The instants when the stimulus (mental task) was administered and when the participant completed the task were recorded.

The experiments were repeated on three different days. The experiments were conducted at the same time each day to reduce variability due to the time of the day.

6 Data Analysis

The first step of the analysis involved identifying the QRS complex. This involved a series of band-pass filters, differentiators and squaring the differentiated signal, a technique described by Pan and Tompkins [14], [15]. This algorithm is based on the slope, amplitude and width of the ECG. An auto-threshold selection was done using *two cluster unsupervised learning using nearest neighbour criteria* described in [16].

Heart rate (HR) was computed by measuring the R-R intervals from the ECG signals using the QRS detected above. Heart rate variability (HRV) was subsequently calculated using the software package *Advanced HRV Analysis* [17].

For the purpose of studying the inter-day variation, data was normalized by considering the first day as the reference point.

7 Statistical Analysis

After extracting the HR from the ECG recordings, statistical analysis was performed to identify the variability and the significance due to the stimulus. The analysis was performed using the Data Analysis tool-pack add-in provided with Microsoft Excel. A Student t-test was performed on the data, which gives the probability that the difference between the two means is caused by chance. It is customary to say that if this probability is less than 0.05, then the difference is ’significant’ and it is not caused by chance. The t-test analysis is appropriate whenever one needs to compare the means of two groups. The t-test is a ratio, with the numerator being difference between the two means or averages and denominator being measure of the variability or dispersion of the scores as expressed below:

$$t - value = \frac{Difference\ Between\ the\ Group\ Mean}{Variability\ of\ the\ Groups}$$

To find the numerator, the difference between the means of the groups is calculated. To find the denominator, which is also called as the standard error of the difference, the variance of each group is calculated and is divided by number of people in the group. By taking the square root of the sum of both the variances we get the standard error. The variance is the average of the square of the distance of each data point from the mean. It is also known as mean squared deviation.

The *t-value* will be positive if the first mean is larger than the second and negative if it is smaller. Once you compute the *t-value* you have to look it up in a table of significance to test whether the ratio is large enough to say that the difference between the groups is not likely to have been a chance. To test the significance, you need to set a risk level called the alpha level. Alpha level is the risk of rejecting the Null Hypothesis when in fact it is true. In other words, stating a difference exists where actually there is none. Alpha risk is stated in terms of probability (such as 0.05 or 5%). The *p-value* is the probability of finding a difference between the two group means and as explained above if this *p-value* is less than 0.05, then the difference is 'significant' and it is not caused by chance.The alpha level was always set to 0.05 for all the t-test performed. A Paired t-test was performed on the mean HR for all the participants paired for:

– *The same question position on different days*.
– *Between different question on the same day*.

A Paired t-test is normally used to compare means on the same or related subject over time or in differing circumstances and it does not assume that the variance of both populations are equal. A two sample t-test with unequal variance was also conducted on the heart rate for each of the participants to determine the overall HRV for an individual on different days.

8 Results

There was a variation of the total number of questions that were answered by the different participants on different days. The minimum questions answered were nine, and hence the first nine questions for each experiment were considered for the paired t-test analysis. The two samples t-test with unequal variance to identify changes between the different days was considered for all the questions answered by the participants on each of the days. Table 1 lists the mean heart rate of all the participants for all the three days. The mean heart rate here implies the average of the participants' heart rate during all the mental tasks conducted on that day. The tables (2, 3, 4) list the p-values for two-tailed distribution analysis of the data for the following

– *Table 2 for identifying changes due to different questions on each of the three days*.
– *Table 3 for identifying changes due to different days*.
– *Table 4 for identifying changes due to each of the questions on different days*.

Table 1. Mean Heart Rate of the all the participants during the mental tasks.

Participant	Day 1 HR	Day 2 HR	Day 3 HR	Day 2/Day 1	Day 3/Day 1
1	100.11	99.96	86.21	0.998	0.861
2	83.43	77.96	75.57	0.934	0.906
3	88.39	81.22	80.27	0.919	0.908
4	75.37	71.34	67.26	0.947	0.892
5	87.92	88.97	84.30	1.012	0.959
6	86.71	78.13	72.59	0.901	0.837
7	86.48	73.55	73.78	0.850	0.853
8	79.98	86.47	70.57	1.081	0.882
9	83.04	83.74	82.29	1.008	0.991
10	89.07	93.23	80.77	1.047	0.907
11	98.43	87.09	81.07	0.885	0.824
12	75.79	68.59	69.08	0.905	0.911
13	82.10	82.25	85.36	1.002	1.040
14	96.52	86.24	95.97	0.894	0.994
15	79.08	75.18	68.89	0.951	0.871
16	78.72	71.49	74.97	0.908	0.952

Table 2. *p-values* of Paired t-test Between Questions on Same Day for all the participants

Question	Day 1	Day 2	Day 3
Q1/Q2	0.0685	0.8166	0.6055
Q2/Q3	0.6044	0.9455	0.0376
Q3/Q4	0.6876	0.2782	0.2611
Q4/Q5	0.4037	0.0996	0.0489
Q5/Q6	0.5541	0.6431	0.1137
Q6/Q7	0.5429	0.9761	0.6027
Q7/Q8	0.5813	0.8892	0.0990
Q8/Q9	0.5937	0.7124	0.4410

Table 3. *p-values* of Paired t-test Between the Mean Heart Rate for all the participants

T-Test Day 1/Day 2	0.013578121
T-Test Day 2/Day 3	0.243691025
T-Test Day 1/Day 3	0.000128381

Table 4. *p-values* of Paired t-test Between the Same Task Order on Different Days for all participants

Question	Day 1 / Day 2	Day 2 / Day 3	Day 1 / Day 3
Q1	0.357610	0.460882	0.035439
Q2	0.055732	0.422769	0.000077
Q3	0.076067	0.228351	0.000106
Q4	0.200562	0.085746	0.000898
Q5	0.018164	0.270949	0.000823
Q6	0.031875	0.596949	0.003855
Q7	0.024736	0.712155	0.013709
Q8	0.022571	0.533416	0.001042
Q9	0.025960	0.728800	0.038138

9 Observations

From Table 1, it is clear that there is a consistent reduction of Heart rate from Day 1 to Day 2 to Day 3 for a significant number of participants. From Table 2, it can be seen that there is no statistically significant change between the HR between two questions on the same day, although there is drop in the HR of the participant over the experiment period.

From Table 3, it is observed that there is a significant reduction in HRV from day one to day two. The change from day two to the third day is much smaller and not significant. This is also confirmed by the two sample T-test of unequal variance. It is also observed (not tabulated) that the average heart rate change between questions on the same day for each participant considering all participants was found to reduce from ± 3.69 on Day 1 to ± 2.60 on Day 3. The two sample T-test assuming unequal variance on the heart rate was also performed for all the questions between the following day pairs (Day 1/Day 2, Day 2/Day 3, Day 1/Day 3), and it showed a weak relationship of HR with all subjects considered.

From Table 4, it is observed that between different days, for the same order of the task, there is small but relatively higher relationship between the HRV compared to the comparison between different questions on the same day.

10 Conclusion

From the experimental results, it has been observed that the mental tasks do cause a variation in the heart rate of the participants. It is also observed that this variation is the greatest on the first day. On the subsequent days, even when the tasks are made more difficult, the variation is smaller. It is also observed that the changes to the variation of the heart rate is from the first day to the second, but from the second to the third the change is relatively small. It is also observed that the intra-day variation of HR for is maximum for the first day, and minimum for the third day, from ± 3.69 to ± 2.60. It is also observed that the HR for different participants was significantly different. For the same participant, the HR for the three days was comparable, even though a reduction from the first day was observed.

Based on the above, the authors conclude that:

- *Absolute values of HR of different people should not be compared.*
- *The HRV reduces when the individual has experienced the experimental stress prior to the experiment.*
- *It is suggested that HRV should not be used to measure the emotional impact of a stimulus on a person as it is possible that they may have got accustomed to the stress and the experiments.*
- *It is not possible for the authors to confirm whether people would get accustomed to overall stressful situations, but it can be stated that when a new stress condition is reapplied, the impact is less than the first application.*

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