The effect of mental stress on heart rate variability

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1 Abstract

Heart rate variability is a topic of great interest because of its medical implications. Decreased heart rate variability is associated with numerous conditions and has been used in risk stratifications for certain diseases. This study examines the relationship between mental stress and heart rate variability. Since mental stress is difficult to quantify, if there exists a relationship between mental stress and heart rate variability, future studies involving mental stress could use heart rate variability as an indicator of mental stress. It was proposed that increased mental stress would lead to decreased heart rate variability. The hypothesis was tested using a 3-lead electrocardiogram. Data was recorded using Biopac Student Lab Pro Version 3.7 and then analyzed using MATLAB 7.0.1. Subjects were put under mental stress by using puzzles, such as Sudoku and anagrams. The results of the testing showed little correlation between mental stress and heart rate variability. 3 of the 7 subjects tested showed decreased heart rate variability in response to mental stress. However, 2 of the remaining subjects showed relatively constant heart rate variability and 2 showed increased heart rate variability, which opposes the proposed hypothesis. Another observed trend showed that subjects whose heart rate variability increased generally had lower baseline heart rates, while subjects who had higher baseline heart rates generally experienced decreased heart rate variability while under mental stress. This indicates that while heart rate variability appears not to be an accurate measurement of mental stress, it still may function well as an indicator of mental stress in subjects with higher baseline heart rates.

2 Introduction

2.1 Significance of Heart Rate Variability

Heart rate variability has long been studied because of its diagnostic uses as a non-intrusive test. [1, 7] Decreased heart rate variability is associated with numerous cardiological and noncardiological diseases, including myocardial infarction, cardiac transplantation, diabetic neuropathy, and tetraplegia. [11, 10, 13, 14, 3]

2.1.1 Myocardial Infarction

Heart rate variability has been used for risk stratification for patients who have suffered from myocardial infarctions, or heart attacks. Risk stratification, or medical decision-making, involves using test results to determine the level of risk that a patient suffers from and, subsequently, develop a plan of action for treating the patient. Decreased heart rate variability has been proven to be associated with increased risk of sudden death after myocardial infarctions. [11]

2.1.2 Cardiac Transplantation

Heart rate variability has been used to monitor cardiac innervation after cardiac transplantation. [13] In one study conducted regarding heart rate variability changes in children after cardiac transplantation, data
showed a decrease in total heart rate variability in patients after cardiac transplantations. [10]

2.1.3 Diabetic Neuropathy

Diabetic neuropathy, a complication of diabetes, is a condition in which hyperglycemia damages the nerves of the patient. [8] Heart rate variability has been used for early detection and treatment of autonomic neuropathy in diabetics. One study concluded that spectral analysis of heart rate variability is a reasonable method of assessing the degree of diabetic neuropathy in patients. [14]

2.1.4 Tetraplegia

Tetraplegia is the paralysis of the arms, legs, and trunk of the body and is usually caused by injury to the spinal cord. Tetraplegics often suffer from autonomic failure as a result of spinal cord injury. Heart rate variability analysis has proven useful in distinguishing between tetraplegics and bodily healthy humans, as decreased heart rate variability is associated with higher level of injury. [3] Heart rate variability is thus practical for stratifying the level of injury suffered by spinal cord injury patients.

2.2 Implications of a causal relationship between mental stress and heart rate variability

A causal relationship between mental stress and heart rate variability would indicate the plausibility of estimating mental stress levels based on heart rate variability. Theoretically, mental stress should influence physical stress. This should be manifested more clearly through measurement of heart rate variability. Since it is difficult to numerically gauge mental stress because of bias in data collection, a proven relationship between mental stress and heart rate variability would provide a quantitative method of analyzing degree of mental stress. [5, 6] This would provide a basis for research into the effects of certain psychological stressors on the health of individuals.

3 Background

3.1 Anatomy of Heart Rate Variability

Heart rate variability is mediated by the autonomic nervous system, which controls homeostasis in the body. The autonomic nervous system comprises of the sympathetic nervous system and the parasympathetic nervous system. (See Figure 3.1)

![Figure 3.1 The Autonomic Nervous System](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/A/autonomic.gif)

Under normal conditions, an increase in heart rate is caused by an increase in activity of the sympathetic nervous system and a corresponding decrease in activity of the parasympathetic nervous system. When the activity levels of the sympathetic and parasympathetic nervous systems change in the opposite way, heart rate decreases. Thus, the sympathetic nervous system and the parasympathetic nervous system function in
contrary action to regulate heart rate variability. [15] Since the autonomic nervous system control heart rate, heart rate variability is a measurement of how well these systems can perform this regulation.

3.2 The Electrocardiogram
Heart rate variability is generally measured using the electrocardiogram to generate an electrocardiograph. The electrocardiogram records electrical impulses sent out by the heart each time it beats. (See Figure 3.2)

The depolarization across the cell membranes of the heart muscle cells spreads throughout the body with each heartbeat. A small residue of the electrical impulses is then detected and amplified by the electrocardiogram. [9] Electrocardiograms can be taken with various numbers of electrodes connected to the body. In the 3-lead electrocardiogram used in this study, electrodes were placed on the left wrist, the right wrist, and the left ankle. This creates a triangle of electrodes that surrounds the heart and ensures accuracy of measurement. (See Figure 3.3)

3.3 Methods of Analysis
Once the electrocardiogram is taken, there are several methods of analyzing the data: time domain, spectral or frequency domain, geometric, and nonlinear. This study utilized time domain analysis of heart rate variability. [11]

3.3.1 Time Domain
Time domain measures of heart rate variability include various statistics that are calculated from the time intervals between heartbeats. Time intervals are determined by the R-R intervals, the period of time between peaks in the electrocardiograph. (See Figure 3.4)
The most common forms of time domain measurement of heart rate variability are the mean and standard deviation of the R-R intervals that do not have any abnormal characteristics. Other measures that are frequently used include the standard deviation of 5-minute average R-R intervals, the means of the standard deviations of all R-R intervals for all 5-minute segments in the reading, and the root mean square of the successive differences in the R-R intervals.

### 3.3.2 Spectral or Frequency Domain

Spectral analysis of R-R intervals involves using Fourier transformations, which decomposes a complex function into various frequencies of oscillatory functions, like the sine and cosine functions. Spectral analysis takes the Fourier transform and splits the graph into different levels of frequency power. (See Figure 3.5)

Different powers of frequency, such as ultra low frequency, very low frequency, low frequency, and high frequency, reflect different physiological modes of regulation of heart rate variability.

### 3.3.3 Geometric

Geometric measures of the R-R intervals use the heart rate variability triangular index. A histogram of the R-R intervals is created, and using a least squares technique, triangles are fitted to the height of each interval. The heart rate variability triangular index is the area of the triangle divided by the area of the modal bin. Bins are the individual categories observed along the x-axis of histograms. The modal bin is the bin in which data points fall most frequently. (See Figure 3.6)
3.3.4 Nonlinear

Nonlinear measures of R-R intervals include the power law slope, the fractal scaling exponent, and the Poincaré plot. The power law slope uses a plot of the log of frequency along the x-axis versus the log of power along the y-axis. This transforms an exponential curve to a linear plot. The slope of the linear plot is positively associated with heart rate variability. (See Figure 3.7)

Detrended fluctuation analysis is a measure of the randomness of R-R intervals. Poincaré plots graph each R-R interval as a function of the next R-R interval. Ellipses are fitted to the graph and the ratio of the short and long axes of the ellipses is SD12. SD12 has been used to identify editing malfunctions that significantly influence the calculation of heart rate variability. (See Figure 3.8)

3.4 Mental Stress

Mental stress results in increases in heart rate, plasma norepinephrine levels, both systolic and diastolic blood pressure, and total peripheral resistance. Examples of psychological stressors include the Stroop test, reaction time tests, mental arithmetic challenges, and public speaking tasks. [2] In one study using Tholos software to create examples of mental stress, researchers also used Sudoku puzzles to create mental stress. [4]

4 Methodology

Seven different subjects aged 17 to 28 were tested to collect electrocardiogram (ECG) data. For each individual subject,
electrodes were attached to three different parts of the body: the left and right wrists, as well as the inner side of the left ankle. (See Figure 4.1)

![Figure 4.1 Electrodes](image1)

Leads were then connected to each of these electrodes, and the other end of the wire was attached to the Biopac MP30 machine. (See Figure 4.2)

![Figure 4.2 Leads attached to Biopac](image2)

The Biopac Student Lab Pro Version 3.7 computer program electronically measured heart rate and displayed the results on an electrocardiograph. The settings on the program were set to an ECG of .5 to 35 hertz on Channel 1, with an acquisition length of ten minutes and a sample rate of 200 samples per second. (See Figure 4.3)

![Figure 4.3 Sample ECG](image3)

The testing area was cleared of distractions and other outside environmental influences. Data was then collected over 600 seconds for each of five separate trials.

**Trial 1.** Baseline: Subjects sat still and relaxed, with both arms resting lightly on the table and legs uncrossed.

**Trials 2, 3, and 4.** Sudoku: Subjects were instructed to play three 600-second online games of Sudoku at increasing levels of difficulty – easy, medium, and hard. During the testing period, subjects were asked to move as little as possible. (See Figure 4.4)
Trial 5. Anagrams: Subjects solved anagram puzzles of consistent difficulty level. Again, subjects were asked to move as little as possible. (See Figure 4.5)

5 Results

In order to analyze the data, the data points taken from the electrocardiographs were imported into MATLAB 7.0.1, in which a program was written to help compile, calculate, and analyze data such as the mean and standard deviation of the R-R intervals. (See Appendix)

Each data file was filtered in order to remove low-frequency composite oscillating waves. Since the QRS waves were high-frequency waves, this filter made the QRS peaks in the electrocardiograph stand out more and facilitated selection in later parts of the program. The program then found the peaks of each graph, and other outliers caused by irregularities were eliminated through the use of a threshold. Ultimately, the mean and standard deviation of the heart rate were calculated and the final data was presented using a histogram. The average mean heart rate, or the average of all the mean heart rates for each test, was also calculated.

Subject 1

The results showed that the baseline standard deviation of 4.9466 was lower than the standard deviation when stimulated by mental stress. The average mean heart rate over the five individual tests was about 69 beats per minute. However, when taking the mental stress tests, the standard deviation of the subject’s heart rate increased with respect to the baseline in all but one test, the hard Sudoku puzzle.

Subject 2

After performing each test, the subject’s baseline standard deviation was higher than when stimulated by mental stress, which supported the hypothesis. The baseline standard deviation of this subject was 8.639, and the average mean heart rate was approximately 77 beats per minute.
Subject 3
The differences in standard deviation for Subject 3 were inconclusive, since some tests showed a heart rate variability that was greater than that of the baseline, while others had a standard deviation that showed decreased heart rate variability. Thus, the baseline standard deviation value of 4.5955 was essentially an average of the standard deviations during the other mental stressors. The average mean heart rate for this subject was 64 beats per minute.

Subject 4
The subject’s baseline heart rate variability of 3.713 beats per minute was fairly consistent while under mental stress. The average mean heart rate was about 71 beats per minute.

Subject 5
There was a significant decrease in standard deviation values under mental stress when compared to the baseline value of 9.1551, and the average mean heart rate of this subject was approximately 84 beats per minute.

Subject 6
The subject’s baseline standard deviation of 6.932 was lower than the standard deviation when under mental stress. The average mean heart rate for this subject was 76 beats per minute.

Subject 7
The results showed that the baseline standard deviation of 4.1045 for this subject was higher than when stimulated by mental stress. The subject had an average mean heart rate of approximately 75 beats per minute.

6 Tables/Figures
(See Figures 6.1, 6.2, and 6.3)

<table>
<thead>
<tr>
<th>Mental Task</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
<th>Subject 5</th>
<th>Subject 6</th>
<th>Subject 7</th>
</tr>
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<tbody>
<tr>
<td><strong>Baselines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEAN</td>
<td>68.3416</td>
<td>81.2983</td>
<td>63.3682</td>
<td>73.0669</td>
<td>85.1504</td>
<td>71.5463</td>
<td>74.6789</td>
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<tr>
<td><strong>Sudoku Easy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STD</td>
<td>5.443</td>
<td>6.1262</td>
<td>5.6597</td>
<td>3.2685</td>
<td>5.8285</td>
<td>6.1917</td>
<td>2.8258</td>
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<tr>
<td>MEAN</td>
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<td>72.6088</td>
<td>87.2057</td>
<td>74.1874</td>
<td>75.746</td>
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<td></td>
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<td></td>
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<tr>
<td>MEAN</td>
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<td></td>
</tr>
<tr>
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<td>83.5427</td>
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<td><strong>Anagram</strong></td>
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<td></td>
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</tr>
<tr>
<td>STD</td>
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<td>5.7112</td>
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<td>3.7425</td>
<td>7.0298</td>
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<tr>
<td><strong>Average Heart Rate</strong></td>
<td>69.18018</td>
<td>76.78658</td>
<td>64.38068</td>
<td>71.33338</td>
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<td>75.74476</td>
<td>74.69158</td>
</tr>
</tbody>
</table>

Figure 6.1: Standard deviation and mean heart rate for the seven subjects over five separate testing environments
Figure 6.2 Visual representation of electrocardiogram data at four different points in the MATLAB program

Subject 1 Baseline Heart Rate
Mean=81.2983 Std=8.639

Figure 6.3 Baseline heart rate histogram for Subject 1
7 Analysis/Discussion

Although there was not enough information present to help determine a definite conclusion, there appears to be little correlation between stress and heart rate variability. Subjects 1 and 6 experienced increased heart rate variability when under mental stress; this did not support the proposed hypothesis. The electrocardiograms of Subjects 3 and 4 showed consistent variability throughout testing, with no conclusive change in their heart rate variability. Subjects 2, 5, and 7 experienced decreased heart rate variability in response to mental stress. This data supported our hypothesis.

Possible causes of error in this experiment include lack of concentration on the part of the subject, periodic outside influences on the subject’s heart rate, and unintended stressors (e.g. emotional, physical, etc.).

However, there was a commonality between the baseline heart rate variability measures of these three test subjects. In these cases, the mean baseline heart rate as well as the initial standard deviation, representative of the heart rate variability, was considerably higher than the heart rates and heart rate variability of the other subjects. The lowest mean average in these three subjects was about 74 beats per minute (Subject 7), whereas the mean baseline heart rate for the subjects that experienced increases in heart rate variability while under mental stress was approximately 71.5 beats per minute. Since the study was not designed to test the existence of a correlation between baseline heart rate variability measures and response to mental stress, we cannot conclusively determine if such a relationship exists. We would highly recommend future studies to examine this relationship.

8 Conclusion

The results of the experiment do not entirely support the proposed hypothesis. Although 3 of the 7 subjects showed a decrease in heart rate variability in response to mental stress, 2 subjects showed no change in heart rate variability and 2 subjects showed increased heart rate variability, which opposes the hypothesis. The data also does not follow trends present in previous studies that have been conducted, which show that increased mental stress leads to decreased heart rate variability. This is an indication that perhaps heart rate variability is not an accurate test of mental stress and should only be used with care in future studies hoping to quantify mental stress.

The data shows a trend in which subjects with lower base heart rates have increased heart rate variability during mental stress and subjects with higher base heart rates have decreased heart rate variability during mental stress. This implies that heart rate variability may only be an accurate method of quantifying mental stress for subjects with higher base line heart rates. However, it is unclear whether or not there exists a correlation between base heart rate and reaction to heart rate variability. Consequently, it would be beneficial to run a second study in order to test this.

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10 References


11 Appendix

Code used for data analysis:

clear
[filename,pathname]=uigetfile('*.txt','*.csv');
fs=200;
dat= load([pathname,filename]);
[r,c]=size(dat);
if c==1;
  t=(1:r)/fs/60;
  data=dat;
else
  t=dat(:,1);
  data=dat(:,2);
end

fs2=100;
[B,A]=butter(1,[15/fs2],''high'');
At=filtfilt(B,A,data);

[~,ploc]=findpeaks(At,'MINPEAKHEIGHT',.5*max(At));

AXIS=[1,2,-.5,2];
subplot(4,1,1)
plot(t,data)
axis(AXIS)

subplot(4,1,2)
plot(t,At)
axis(AXIS)

subplot(4,1,3)
plot(t,(data),t(ploc),data(ploc),'
o')
axis(AXIS)

L2=ploc(2:end);
L1=ploc(1:(end-1));
Dis=12000./(L2-L1);
t2=t(ploc);
t2=t2(2:end);
subplot(4,1,4)
plot(t2,Dis)

meandis=mean(Dis);
stddis=std(Dis);

s=std(Dis);
Dis=Dis(Dis< (m+4*s));
Dis=Dis(Dis> (m-2*s));

figure
hist(Dis,15)
title(['Mean=',num2str(meandis),'
Std=',num2str(stddis),'
',filename(1:(end-3))])
ylabel('Samples')
xlabel('Beats per Minute')