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Measuring Task-related Changes in Heart Rate Variability

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Abstract— **Small beat-to-beat differences in heart rate are the result of dynamic control of the cardiovascular system by the sympathetic and parasympathetic nervous systems. Heart rate variability (HRV) has been positively correlated with both mental and physical health. While many studies measure HRV under rest conditions, few have measured HRV during stressful situations. We describe an experimental protocol designed to measure baseline, task, and recovery values of HRV as a function of three different types of stressors. These stressors involve an attention task, a cold pressor test, and a videotaped speech presentation. We found a measurable change in heart rate in participants (n=10) during each task (all p's < 0.05). The relative increase or decrease from pre-task heart rate was predicted by task (one-way ANOVA, p=0.0001). Spectral analysis of HRV during the attention task revealed consistently decreased measures of both high (68±7%, mean±S.E.) and low (62±13%) frequency HRV components as compared to baseline. HRV spectra for the cold pressor and speech tasks revealed no consistent patterns of increase or decrease from baseline measurements. We also found no correlation in reactivity measures between any of our tasks. These findings suggest that each of the tasks in our experimental design elicits a different type of stress response in an individual. Our experimental approach may prove useful to biobehavioral researchers searching for factors that determine individual differences in responses to stress in daily life.**

I. Introduction

In the 18th century, Albrecht von Haller made the first observation that the beat of a healthy heart is not entirely regular [1]. The phenomenon von Haller was a witness to is now commonly referred to as heart rate variability (HRV). HRV describes the small beat-to-beat differences in heart rate and is a result of the dynamic control of the cardiovascular system by the autonomic nervous system (ANS). The two branches that comprise the ANS and often interact antagonistically are the excitatory sympathetic nervous system (SNS) and the inhibitory parasympathetic nervous system (PNS). These two branches are responsible for modulating individuals' physiological arousal and their capacity to meet the demands of both mental and physical stress. The ability of the ANS to rapidly transition between high and low arousal states provides an individual with the ability to match an appropriate physiological response to a specific situation.

Higher HRV has been linked to creativity, psychological resilience, and a more developed capacity to regulate affective, cognitive, and physiological responses to stress [2],[3]. In contrast, low HRV is linked to anxiety disorders, depression, and cardiovascular disease [2], [4]-[6]. Many empirical studies involving HRV measure the balance between sympathetic and parasympathetic control of heart rate in a person at rest. Inhalation temporarily gates the parasympathetic influence and causes heart rate to increase. Exhalation restores the parasympathetic influence and heart rate decreases. The resulting periodic changes in heart rate, known as respiratory sinus arrhythmia, serve as a useful reference for estimating autonomic balance. In university students, higher levels of resting respiratory sinus arrhythmia have been associated with the use of more constructive coping strategies [2].

While HRV measured under rest conditions has become a common indicator of autonomic balance, less is known about the relationship between HRV and sympathetic arousal arising from confrontation with a stressful environment. One promising study found a statistically significant relationship between HRV levels before, during, and after a mental arithmetic task. Power spectral analysis revealed decreases in parasympathetic and sympathetic influences during mental stress followed by concomitant increases in both back to baseline within five minutes of the mental task [7].

The present study will attempt to quantify changes in HRV that arise in three different situational contexts – an attention task, a cold pressor test, and a speech presentation. We intend to develop a measurement technique that can be used to assess stress response in individuals by those interested in biobehavioral research. More specifically, we will determine if there is a statistically significant change in either high or low frequency measures of HRV or in average heart rate during and after the three tasks. We will also assess whether there are quantifiable differences in participant reactivity that can be attributed to the particular type of stress induced by each task.

II. Methods

A. Experimental Protocol

Healthy male participants, aged 18-24, were recruited on the Tulane uptown campus to participate in the study. Each participant was fitted with a Holter monitor (Forest Medical) that is used to record a continuous ECG. Participants remained seated for the duration of the study. Each was asked to complete a series of tasks designed to elicit

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particular types of physiological arousal. The tasks included an attention task, a cold-pressor test, and a videotaped speech. A ten-minute recovery period was imposed between tasks to allow autonomic tone to return to baseline levels. The Institutional Review Board at Tulane University has approved this experimental protocol.

The attention task is a 5 minute computerized pattern-matching test involving sequences of numbers flashed on the screen at a challenging rate. The cold pressor test involves an ice pack being placed around the participant's bare forearm for up to two minutes creating an unpleasant or mildly painful sensation. The speech presentation is a videotaped impromptu speech with a two-minute preparation time and a three-minute duration of the presentation. The participants are asked to speak about their personal strengths and weaknesses.

B. Data Analysis

Data was downloaded onto a laptop computer and analyzed with the Trillium Gold 5000 software suite (Forrest Medical). Following guidelines put forth by the European Task Force [8], we chose to use frequency domain analysis techniques to investigate the high and low frequency components of the sequence of automatically detected interbeat intervals. High frequency (HF) components of this signal are primarily related to PNS activity while low frequency (LF) components are a combination of PNS and SNS activity. A moving 5-minute window was used to calculate frequency spectra at one-minute intervals for the duration of the experiment. Each of the spectra contains information beginning at the indicated time and extending for the next five minutes. Total power in the HF (0.15-0.40 Hz) and LF (0.04-0.15 Hz) ranges were recorded. Heart rate was similarly averaged over five minute intervals.

In Figure 1 we illustrate the time course of the data extracted from the Trillium software before, during, and after the speech presentation for one participant. The values used in our statistical analysis are comprised of the HR, HF, and LF components in the five minutes before beginning each task, the first 5 minutes of each task, and the five minutes immediately after the end of each task. Reactivity is measured both in terms of the actual measurements and also as a ratio of in-task to pre-task values of each of the three measured quantities. We will refer to this ratio as the reactivity ratio.

We designed the protocol to measure a biphasic response to each task. From rest, the participant should exhibit some autonomic response to the task followed by a rapid recovery at the end of the task. We test this assumption by comparing reactivity across participants for each task using a repeated measures model to determine if there is a quadratic (or biphasic) response that is not participant specific (SPSS 14.0, SPSS Inc.). We also used a one-way ANOVA (JMP 5.1, SAS Institute) to investigate the possibility that each task elicits a distinct pattern of response using the reactivity ratio as the dependent variable and task as an independent variable. Finally, we calculated the correlations between each of the reactivity ratios for each task. For all statistical tests we use $p < 0.05$ as our standard for significance.

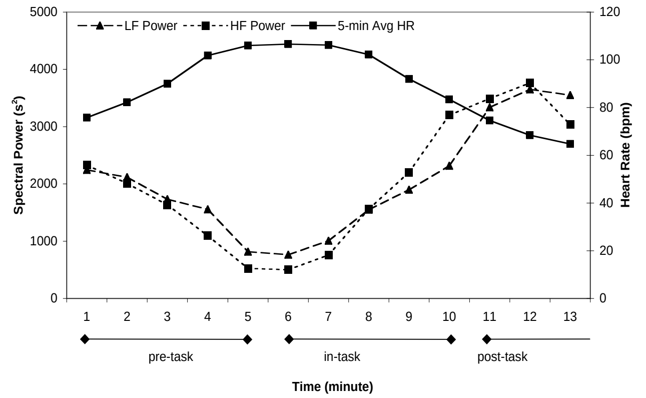

Fig. 1 - Time course of heart rate, LF power, and HF power before, during, and after speech presentation for one participant. Each data point is calculated with a 5-minute window and plotted at the beginning of the window. Thus, the average heart rate at t = 2 minutes on the graph includes a data window from 2-7 minutes. Values used in statistical analysis are taken at the beginning of each 5-minute segment (in this case: pre-task reactivity is recorded at t = 1 minute, in-task at t = 6 minutes, and post-task at t = 11 minutes).

III. RESULTS

With a relatively small sample of participants (n = 10), we were able to describe the main effects of the experimental protocol on physiological arousal in our participants. The mean values of all HR, HF, and LF measurements are listed in Table 1. We used a repeated measures model to assess whether the protocol was able to elicit and measure both response and recovery in participants. Measurements of HR demonstrate an increasing quadratic tendency during the attention ($p = 0.022$) and speech ($p = 0.004$) tasks and a decreasing quadratic tendency during the cold pressor task ($p = 0.003$). The LF reactivity also demonstrated a decreasing quadratic tendency during the attention task ($p = 0.020$) and exhibited a trend towards a decreasing quadratic tendency in the cold pressor task ($p = 0.056$). The LF reactivity to the speech task was found to have a significant linear tendency ($p = 0.030$) that might indicate that subjects had not returned to their baseline autonomic state during the time that recovery measurements were taken for this task.

Table 1 – Mean physiological measurements

Task	**HR**	**LF**	**HF**
<u>Attention</u>			
Baseline	78.6 ± 4.3	1320 ± 430	1900 ± 1120
Task	81.5 ± 4.1	860 ± 260	1050 ± 690
Recovery	79.4 ± 4.3	2380 ± 800	2760 ± 1240
<u>Cold pressor</u>			
Baseline	77.7 ± 4.1	2430 ± 830	2060 ± 1070
Task	74.6 ± 3.9	1480 ± 420	1990 ± 1250
Recovery	77.6 ± 4.1	2050 ± 620	1720 ± 780
<u>Speech</u>			
Baseline	79.1 ± 4.7	1400 ± 520	1470 ± 790
Task	89.4 ± 5.5	1500 ± 380	2210 ± 960
Recovery	76.0 ± 4.4	1770 ± 580	2010 ± 1120

Mean ± S.E.

Table 2 – Mean reactivity ratios

Task	HR	LF	HF
Attention	1.04 ± 0.02*	0.68 ± 0.07*	0.62 ± 0.13*
Cold pressor	0.96 ± 0.01*	0.88 ± 0.16	1.06 ± 0.20
Speech	1.13 ± 0.03*	2.08 ± 0.72	2.89 ± 1.28

Mean ± S.E.

*Mean ≠ 1 ($p < 0.05$)

Task-related changes in HRV are also measured by calculating the reactivity ratio (task:baseline). Shown in Table 2, these calculations are consistent with the repeated measures results above. The HR reactivity ratio was found to be greater than 1 ($p < 0.05$) for all measures found to have an increasing quadratic tendency and less than one for measures found to have a decreasing quadratic tendency. The speech task elicited large responses as measured by the reactivity ratios but these responses were characterized by large variance between participants.

A one-way ANOVA test revealed that task is a significant predictor of HR reactivity ratio ($p < 0.0001$) while also showing a non-significant trend to predict the HF ($p = 0.095$) and LF ($p = 0.061$) reactivity ratios. In comparing reactivity ratios, we found that no measure was correlated to any other during the attention task. However, the LF and HF reactivity ratios were significantly correlated to one another in both the cold pressor task ($r = 0.74$, $p = 0.014$) and the speech task ($r = 0.94$, $p = 0.0001$).

IV. Discussion

Our primary goal is to verify that autonomic responses to stress-inducing tasks can be evaluated by short-term measures of heart rate. In the present study, we present evidence demonstrating that the experimental protocol we have described reliably elicits measurable changes in heart rate in response to three tasks. In addition, we have begun to explore the complex and interdependent nature of indirect measures of autonomic tone as they relate to physiological reactivity.

Our experimental protocol was designed with a belief that physiological responses to short duration stressors in the environment would occur within a time frame of less than five minutes. Our data support this assumption. In Fig. 1 the physiological measures appear to plateau shortly before the end of the speech task. Similarly, most measurements returned to baseline levels within a five-minute recovery period (see Table 1). Using repeated measures analysis, we demonstrate that the average response in heart rate to each task can be represented by a quadratic, or two phase, model of reaction and recovery. The only exception to this conclusion is that we found some indications of a shift in baseline in measurements during the recovery period after the speech task.

The speech task is characterized by large changes in the HF and LF components of heart rate variability that suggest elevated levels of physiological arousal in an individual. The five-minute speech task includes a two-minute preparation period and a three-minute speech. These two components may affect heart rate in different manners. While anxiety is should persist from the preparation time through the end of the five minute task, the speech component will also involve changes in breathing patterns. These changes in breathing will alter the occurrence of respiratory sinus arrhythmia in the participant and consequently the measures of HRV.

Our results also indicated a baseline shift in some components of HRV after the speech task. Due to the interpersonal nature of this task, it seems likely that participants may continue to self-evaluate their performance for some time after the task ends. This is less likely to occur after the other tasks. Thus, we conclude that a 5-minute recovery period is not sufficient for the participant to return to a baseline condition after this type of extreme arousal. In the present study, the speech task was the last of the three tasks and the lack of sufficient recovery time does not affect any of our results.

Statistical analysis of the variance in our measured data reveals that the specific task may predict the physiological reactivity of the participant. In other words, each of our three tasks may elicit a unique cardiovascular response in the participants. The attention task increases heart rate with uncorrelated decreases in LF and HF components of HRV. Ingrid, et al. reported a similar finding [7]. The cold pressor task decreases heart rate with correlated changes in LF and HF components of HRV. The speech task increases HR with correlated changes in LF and HF. The differences in these responses to our three tasks demonstrate that the effects of stress depend on the nature of the stressor.

Understanding the physiological responses of each task will involve a determination of the underlying reactivities of the sympathetic and parasympathetic nervous systems that combine to define a cardiovascular set point. High frequency components of heart rate variability are believed to be mediated by changes in parasympathetic activity while low frequency components of HRV are likely due to a combination of sympathetic and parasympathetic mechanisms. Thus, it is possible that some of the variance in reactivity that we describe could be due to individual differences in autonomic response to these types of tasks.

While an investigation of the determinants of individual reactivity is beyond the scope of the present study, we have collected a few simple measures of hostility, anxiety, depression, and a sense of personal mastery. We plan to explore the links between psychological characteristics and physiological measures of reactivity in a future study. The ability to measure task-related changes in heart rate variability may one day help biobehavioral researchers to determine the mechanisms by which individual differences in response to stress can lead to an increase or decrease in risk of cardiovascular disease.

At present, we can conclude that the protocol used in this study is able to reliably elicit three distinct types of physiological reactions that can be detected by short-term measurements of heart rate. We are eager to continue to explore the role of the autonomic nervous system in producing these specific physiological reactions.

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