Decreased Long Term Variations of Heart Rate Variability in Subjects with Higher Self Reporting Stress Scores

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Abstract— **Heart rate variability (HRV) has been well established to measure instantaneous levels of mental stress. Circadian patterns of HRV features have been reported but their relationships to mental stress were not studied explicitly for estimating stress levels. In this study, we investigated long term variations of HRV features to provide a reliable measure of chronic stress levels. Twenty three subjects were divided into high (n=10) and low stress group (n=13) depending their self-reporting stress scores. HRV features were calculated during five different time periods of the day. High stress group showed decreased overall variations of HRV features but similar median values to low stress group. Compared to normal sinus rhythm data during each time period, high stress group showed significantly less % difference of HRV patterns than low stress group. Our data suggested that long term variations of HRV features might be more useful to detect subjects under chronic stress.**

Keywords-component; mental stress; heart rate variability; Stress Response Inventory; long term rhythm

I. INTRODUCTION

Chronic stress increases susceptibility to negative health outcomes and involves alteration in behavior, autonomic function and the secretion of hormones such as cortisol [1]. Stress changes the physiological balance of autonomic nervous system (ANS). The ANS is divided into two main divisions: sympathetic and parasympathetic nervous system. Both components operate simultaneously and balance each other dynamically in normal situations. When the stress is given, sympathetic system dominates to increase the heartbeat rates, the perspiring activity of adrenal glands, and breathing rates. To recover from the stress, parasympathetic system takes over to decrease the heartbeat, sweating, and breathing rates.

Heart rate variability (HRV) refers to the beat-to-beat alternations in heart rates. HRV is directly associated with the mortality of cardiac patients and diabetic neuropathy [2]. Mental stress decreased HRV features such as high frequency components but increased low frequency components. Thus, HRV analysis has been established as an instantaneous quantitative measure of ANS activity [3]. However, its use in the daily life to monitor chronic stress levels is still limited due to the lack of reliability compared to more conventional methods such as self reporting stress questionnaires and clinical interviews.

Stress questionnaires have been used to measure stress levels of individuals in clinical practice and psychological research. Each questionnaire has different characteristics and purposes. In general, questionnaires are used to measure the degree of symptoms, thoughts, feelings, experiences and so on. Stress response inventory (SRI) has been recently devised to score the severity of stress-related symptoms experienced during the previous two weeks that may influence the current status of mental stress. SRI consists of 39 items that focus on the emotional, somatic, cognitive, and behavioral stress responses. SRI scores could be categorized into seven stress factors: tension, aggression, somatization, anger, depression, fatigue, and frustration. Thus, the SRI offers a reasonable method to estimate the levels of chronic stress [4].

The circadian variability of physiological phenomena is well known in the cardiovascular system [5, 6]. Daily variability was studied in sudden cardiac death [7] and myocardial ischemia [8]. Circadian rhythms of ANS under stress were also recently investigated in a few studies: cardiac ANS activity was different while awake and asleep in paramedic workers on the off duty day but not different on the on duty day, suggesting suppressed long term patterns under stress [9]. HRV values were diminished in mice under chronic stress caused by low frequency noise [10] and in swine caged together [11]. In our study, differences of long term HRV patterns between low and high stress groups were investigated to provide a preliminary evidence for the reliable measurement of chronic mental stress levels. Subjects were divided into high and low stress group based on their SRI scores and their HRV features were measured at multiple time points.

II. METHODS

A. *Subjects and Data Acquisition*

Twenty three students in their 20s and 30s of ages participated in the experiment carried out in Information and Communications University, Daejeon, Korea. Subjects filled

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out the simplified version of SRI questionnaire which was composed of 22 questions [12]. Each question was scored according to the five point Likert score format and total SRI scores were calculated.

HRV feature data were obtained using two models of photoplethysmography (PPG) sensors (Freeze-Framer™, HeartMath LLC, Boulder Creek, CA and a proprietary sensor, Samsung Electronics Co. Ltd, Suwon, Korea). The sensor was placed under the tip of the index finger while the subject sat in the comfortable chair. Three minute heartbeat records were obtained in each measurement. Each subject took at least three measurements during five time periods that consisted of one morning session from 9 AM to 12 noon; two afternoon sessions from noon to 3 PM and from 3 PM to 6 PM; two evening sessions from 6 PM to 9 PM and from 9 PM to 12 PM. Measurements were not carried out from 12 PM to 9 AM.

B. Data Processing and Analysis

Fourteen HRV metrics were calculated from the heartbeat interval data of PPG sensors using our previously developed software [13, 14, 15]: mean heart rate (Mean HR), mean heartbeat intervals (Mean RR) , standard deviation of the RR-intervals between normal beats (SDNN), coefficient of variation (CV), root mean square of successive differences (RMSSD), and % heartbeat intervals with difference in successive heartbeat intervals greater than 50 ms (PNN50) as time domain features; HRV index (HRV Index, bin width of 8.0 ms), triangular interpolation of R peak intervals histogram (TINN), and stress index (SI) as geometrical analysis features; and low frequency (LF), high frequency (HF), the ratio of LF to HF (LF/HF), normalized LF (LFnu), and normalized HF (HFnu) components as frequency domain features [2]. HRV features obtained during the same time period were averaged per subject.

The correlations between HRV features averaged over all time periods and SRI scores were calculated by the Pearson's correlation analysis (StatGraphics Plus V4.1). Subjects were divided into high and low stress groups by using the k-means clustering method based on Euclidean distance of total SRI scores (StatGraphics Plus V4.1, Manugistics, Inc, Rockville, MD). The long term variations of HRV features were compared between two groups by using F-test (StatGraphics Plus V4.1). Finally, HRV features in low and high stress group were compared by Mann-Whitney test (StatGraphics Plus V4.1).

The long term patterns were obtained from 18 ECG data sets from Physionet Normal Sinus Rhythm (NSR) database [16] and tested for quadratic curve fitting. Based on the fitted standard NSR curve, a % difference score of each HRV feature was defined as the sum of % differences between the subject HRV values and standard curve values at each time point. The % difference scores of HRV features were compared using Wilcoxon matched pair signed rank test between low and high stress group (StatGraphics Plus V4.1). Test results were considered significant if p-value was less than 0.05 (95% confidence level).

III. RESULTS

SRI scores did not show any significant correlation with any average HRV features of subjects (data not shown).

Subjects with SRI scores greater than 18 were classified as high stress group (n=10, ave. ± st. dev.: 32.3 ± 4.6) and the rest were classified as low stress group (n=13, 6.1 ± 1.5) using k-means clustering (p<0.05).

Long term HRV variations of both groups were compared to show significantly decreased variances in SDNN, RMSSD, PNN50, HRVIndex, TINN, SI, LF, and HF and increased LF/HF in high stress group (F-test, Table I). In comparing the median values, no features showed difference in two groups (Mann Whitney test, p>0.05, *data not shown*).

The standard curve obtained from NSR datasets were overlaid as reference onto the HRV features obtained from multiple time periods (Fig. 1). In most of HRV features, low stress group showed larger positive deviance from the NSR curve compared to high stress group that showed larger negative deviance except in LF/HF that showed the reversed trend.

The % difference score of each HRV feature was summarized in Table II. High stress group showed significantly decreased HRV features compared to low stress group in all HRV features (Wilcoxon signed rank test, p<0.05)

TABLE I. COMPARISON OF VARIANCES OF HRV VALUES IN LOW AND HIGH STRESS GROUP (F-TEST)

HRV features	Low Stress Group (n=13) Mean ± S.E.	High Stress Group (n=10) Mean ± S.E.
SDNN*	0.053 ± 0.003	0.053 ± 0.002
RMSSD**	0.034 ± 0.002	0.033 ± 0.001
PNN50**	13.64 ± 1.48	12.11 ± 1.06
HRVIndex*	14.30 ± 0.63	13.42 ± 0.50
TINN*	0.24 ± 0.01	0.22 ± 0.01
SI**	32.72 ± 4.17	24.86 ± 2.84
LF*	1,068.6 ± 120.77	860.46 ± 87.57
HF**	906.11 ± 101.04	709.51 ± 61.46
LF/HF**	1.48 ± 0.12	1.85 ± 0.25

*P<0.05, **P<0.005
S.E. : STANDARD ERROR

TABLE II. COMPARISON OF THE % DIFFERNCE SCORES OF LONG TERM HRV VALUES BETWEEN LOW AND HIGH STRESS GROUP

HRV features	Low Stress Group (n=13)		High Stress Group (n=10)
SDNN	-15.00	>	-25.77
RMSSD	-8.51	>	-32.81
PNN50	124.93	>	95.24
HRVIndex	60.14	>	5.16
TINN	89.17	>	17.88
SI	-71.37	>	-98.95
LF	-35.58	>	-112.39
HF	-129.96	>	-189.84
LF/HF	111.15	<	137.82

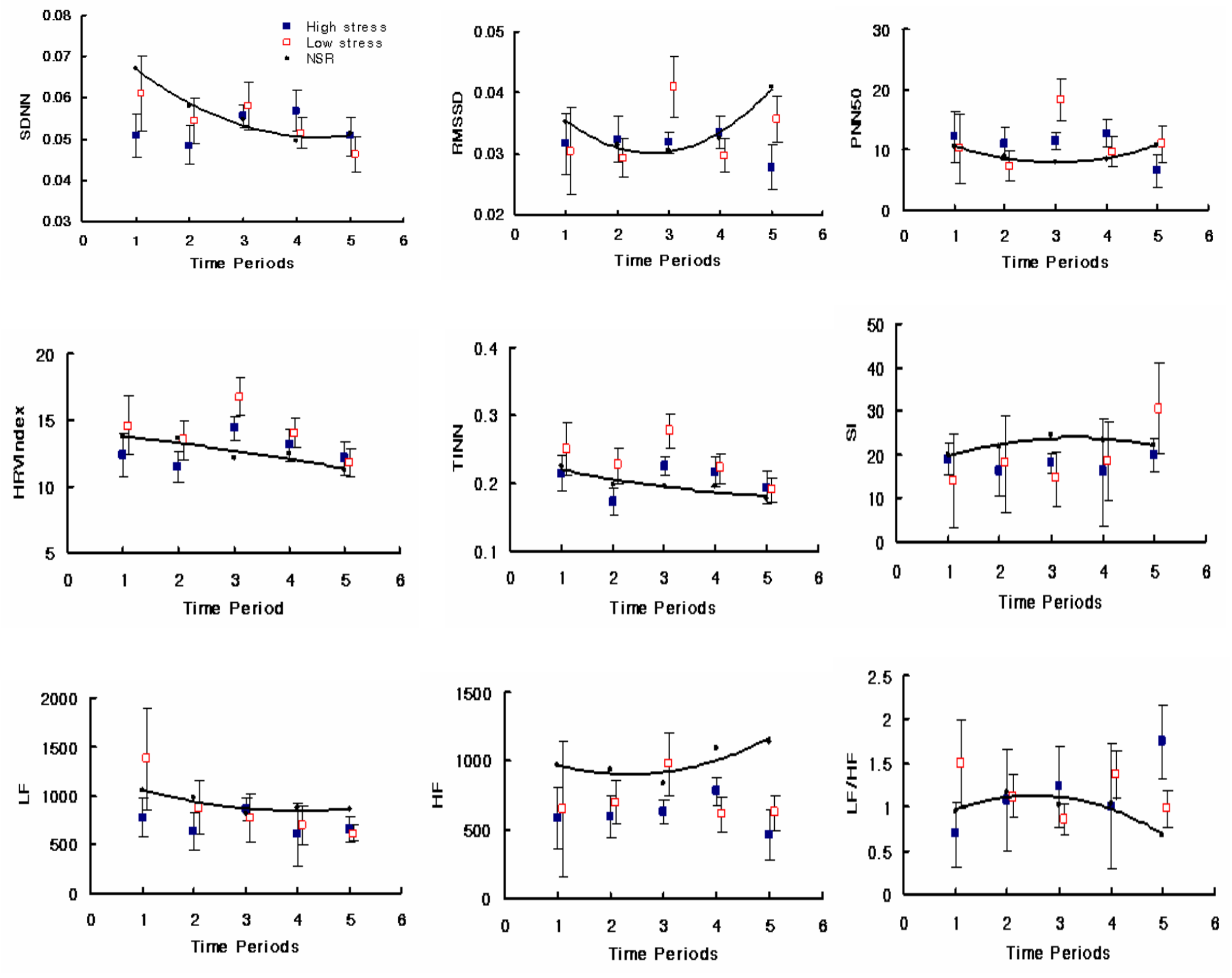

Figure 1. HRV features showing significantly decreased long term variations in high stress group (solid square) compared to low stress group (hollow square) measured at five different time points. Normal sinus rhythm (NSR) data (small dots connected with the fitting line) offer a standard long term pattern that works as a reference to calculate the % difference of HRV features. Time period 1: morning session (9AM~NOON); 2: early afternoon (NOON~3PM); 3: late afternoon (3PM~6PM); 4: early evening (6PM~9PM); 5: late evening (9PM~12PM).

except LF/HF that showed increased values.

IV. Conclusions and Discussion

Long term variations in high stress group showed significantly decreased variances that indicated somewhat disturbed ANS rhythms under the influence of chronic stress. None of median HRV features were significantly different between high and low stress group, which suggests multiple measurements without considering the time point of HRV data acquisition during the day may not provide a good estimation of mental stress levels. Upon analyzing long term variations of HRV features of our subjects with respect to the standard NSR curve of HRV features, the new % difference measure of long term HRV patterns was devised and provided more consistent results than median HRV features. Our data suggested that HRV analysis performed at multiple time points could be used to detect subjects under the mental stress.

In this experiment, HRV features of our student subjects did not show the similar pattern to the standard curves of NSR subjects who are presumably regular workers. The trough HRV values in RMSSD and PNN50 occurred during the early morning and late evening periods suggested that subjects in low stress group were most stressful during these time periods, whereas the peak values occurred during the late afternoon period suggested that they were often most relaxed during this time period. These trends might represent life styles uniquely found in our student subjects. Since various groups of subjects might have different long term HRV patterns, it would not be straightforward to devise single measure that represents an overall deviance from the normal long term HRV patterns.

Current experiments were performed in the laboratory at the heartbeat measuring stations. Several previous studies have proposed the use of portable sensing devices in cardiac applications [17]. Since multiple measurements at rather specific time periods are required in our approach, it would be more convenient if the measurement can be performed in mobile settings using portable heartbeat sensors. However, there seems to be still numerous problems in measuring heartbeats in mobile applications for estimating mental stress levels. One of them is signal degradation while the subject is moving that may result in wrong heartbeat interval detection [18]. Furthermore, it might not be convenient to measure heartbeats for three or longer min for each time period. Ultra short term analysis has been thoroughly investigated in previous studies [15, 19], that warranted a further study to see if long term patterns could be reproduced even by ultra short term analysis of HRV features [20].

According to our current results, previously reported pervasive heartbeat or ECG sensors could be used for the short and intermittent recordings to estimate the stress level of individuals. For example, short ECG segments might be sampled through normal clothing by ECG electrodes attached to the back of a chair [21]. The accumulated week long data can be categorized into different time periods, averaged, and used to calculate the % deviance from the normal HRV patterns that will indicate the stress levels of the individual.

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