Impact of Mental Stress on Heart Rate Asymmetry

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Abstract

This article studies the impact of mental stress induced by open-road driving on heart rate asymmetry (HRA), a physiological phenomenon that quantifies imbalance of heart rate acceleration and deceleration. Using ECG data of 10 individuals from a retrospective database from Physionet, three common HRA indexes (i.e., Porta Index-PI, Guzik Index-GI, and Slope Index-SI) were calculated within five minutes time windows across different stress levels. Results revealed that on average HRA significantly reduced by 2.1% with stress level (p<0.05) and HRA was lower in high stress, compared to moderate and low stress. Further pairwise comparison revealed that PI was significantly different between low and moderate stress (p=0.004) as well as moderate and high stress (p=0.047). Also, GI and SI were independent discriminators between low and moderate stress (p<0.001), and low and high stress (p<0.001). These results suggest that HRA can be used as a new biomarker for stress assessment.

1. Introduction

Stress causes negative impacts on health [1] and can lead to a decline in human performance [2, 3]. In more sever stages, stress can cause progression in diseases (e.g. cardiovascular diseases and hypertension) [1, 4] or delay recovery from injuries (e.g. delay in wound healing in diabetes patients [5]). Although evidence exists of adverse health outcome due to stress, a recent survey by American Psychological Association reported that stress level remained unchanged or increased in 72% of surveyed Americans over the past five year [6].

Stress activates sympathetic nervous system and deactivates parasympathetic nervous system and as a result alters autonomic nervous system balance [7-9]. Therefore, objective assessment of acute stress through physiological signals such as heart rate and heart rate variability (HRV) gained lots of attention recently. Especially advances in wearable sensors and mobile health provided a great opportunity for stress assessment and its timely management during activities of daily living. Stress assessment and management can, therefore, be utilized to reduce or prevent above mentioned negative effects of stress.

Previous studies have demonstrated that stress reduces HRV [10], but less is known about the impact of stress on heart rate asymmetry (HRA), a new approach that quantifies increase or decrease of heart rate with respect to previous beat [11, 12].

Since HRA is corresponding to unequal contributions of accelerations and decelerations in heart rate [11], it is hypothesized that stress can affect HRA. Therefore, the goal of this article is to study the impact of stress on HRA using recorded data within uncontrolled environment.

2. Data and method

2.1. Data

The electrocardiogram (ECG) data was employed from a retrospective database from Physionet, Stress Recognition in Automobile Drivers database, [13, 14]. Physiological data (ECG, electromyography, hand and foot galvanic skin response, and respiration rate) were recorded while sitting in a car and driving in city and highway. ECG was recorded with a sampling frequency of 496 Hz in a modified lead II configuration. Modified lead II was used to reduce the effect of motion artifacts, to better detect QRS peaks.

Using a validated questionnaire analysis in the original research [14], sitting inside a car, highway driving, and, city driving were marked as low, moderate, and high stress, respectively. ECG Data from 10 out of 17 individuals was used here. Seven datasets were excluded due to a lack of timing information for different conditions (e.g. sitting in car, street driving, and highway driving). Using time interval's information provided in a previous study [15], the first five minutes of each segment were extracted for further analysis. Five minutes interval was selected as recommended in taskforce guidelines for short term HRV analysis [16].

2.2. Method

2.2.1. QRS detection

QRS peaks were detected using the Pan–Tompkins algorithm [17], and the output from the algorithm manually inspected by an expert for possible undetected/miss-detected QRS peaks. Detected QRS peaks were used to create RR interval series.

2.2.2. Heart rate asymmetry

HRA can be observed visually in Poincaré plot (plot of each RR interval against next RR interval). Specifically, uneven distribution of points above and below identity line (IL) is known as HRA [12, 18]. In Poincaré Plot, IL corresponds to ΔR=0, where $\Delta R = RR_{n+1} - RR_n$ (RR_n is the n^{th} RR interval). Furthermore, points above IL (PA=ΔR>0) and below IL (PB=ΔR<0) correspond to deceleration and acceleration of heart rate, respectively. To quantitatively represent HRA, three common HRA indexes were calculated, including Porta Index [19], Guzik Index [12], and Slope Index [18] within five minutes time windows across different stress levels:

1- Porta Index (PI): an index that quantifies the distribution of points in Poincaré Plot with respect to IL and is a representation for prevalence of acceleration of heart rate [19]:

$$PI, [\%] = \frac{n_{PB}}{n_{PA} + n_{PB}} \times 100$$

where, n_{PA} and n_{PB} are number of points above and below IL.

2- Guzik Index (GI): an index based on magnitude of the difference between consecutive RR intervals, which is defined as a percentage of the distance of points above IL with respect to the total distance of all points with respect to IL [12]:

$$GI, [\%] = \frac{\sum_{i=1}^{n_{PA}} d_i^+}{\sum_{i=1}^{n_{PA}} d_i^+ + \sum_{i=1}^{n_{PB}} d_i^-} \times 100$$

where, d_i^+ and d_i^- are distance of points above and below IL from identity line, respectively.

3- Slope Index (SI): an index based on the phase angle of points in Poincaré plot, which is defined as a percentage of phase angle difference of points above IL with respect to the total phase angle difference [18]:

$$SI, [\%] = \frac{\sum_{i=1}^{n_{PA}} \Delta\theta_i}{\sum_{i=1}^{n_{PA}} \Delta\theta_i + \sum_{i=1}^{n_{PB}} \Delta\theta_i} \times 100$$

where, $\Delta\theta_i = \theta_{IL} - \theta_i = 45^\circ - \theta_i$ and $\theta_i = \text{atan}(\frac{RR_{n+1}}{RR_n})$. θ_i is the phase angle of consecutive RR intervals (RR_n, RR_{n+1}).

2.2.3. Statistical analysis

Conditions with different stress levels were compared using analysis and variances (ANOVAs) and post-hoc least significant difference (LSD); the level of statistically significance was set to 0.05. Cohen's d effect size was calculated to compare the mean differences between groups with the different level of stress; values of 0.2, 0.5, and 0.8 were, respectively, considered as small, moderate, and large effect size [20]. Furthermore, Pearson's correlation was employed for studying the correlation between different HRA indexes. Correlation of 0.20-0.29, 0.30-0.39, 0.40-0.69, and 0.70-1.00 were respectively considered as weak, moderate, strong, and very strong [21]. All statistical tests were performed in SPSS (IBM, version 21, Chicago, IL).

3. Results

Mean and standard deviation of HRA indexes are reported in Table 1. Furthermore, the changes in these parameters across groups with the different stress level are visually depicted in Figure 1. Results of ANOVA and pairwise comparison are summarized in Table 2. Cohen's d effect size is also reported in this table.

Table 1. Mean and standard deviation of HRA indexes across groups with different stress level.

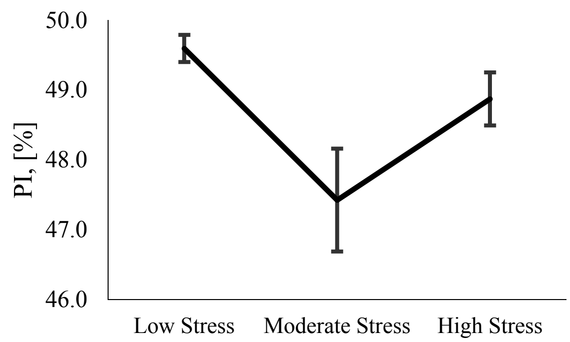
	Stress Level		
	Low Stress	Moderate Stress	High Stress
PI, [%]	49.60±0.62	47.42±2.33	48.87±1.20
GI, [%]	50.75±0.45	50.04±0.44	49.75±0.38
SI, [%]	50.81±0.39	50.04±0.45	49.73±0.41

PI: Porta Index, GI: Guzik Index, SI: Slope Index

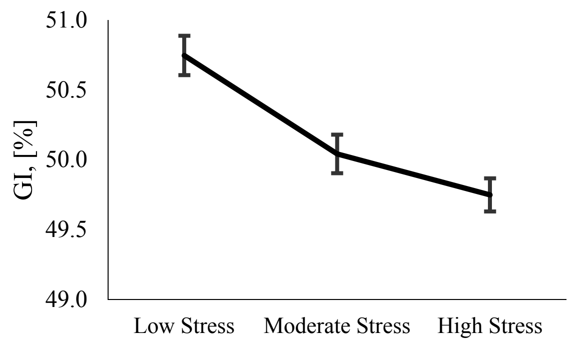
Table 2. ANOVAs, and Cohen's d (d) for pairwise comparison of the HRA indexes for between group differences (statistically significant cases marked in bold).

		Pairwise comparison		
	ANOVA	Low & Moderate Stress	Low & High Stress	Moderate & High Stress
PI, [%]	**p= 0.014**	**p= 0.004** d= 1.28	p= 0.309 d= 0.77	**p= 0.047** d= 0.78
GI, [%]	**p= 0.001**	**P< 0.001** d= 1.59	**p<0.001** d= 2.40	p= 0.130 d= 0.71
SI, [%]	**p= 0.001**	**p<0.001** d= 1.83	**p<0.001** d= 2.70	p= 0.111 d= 0.72

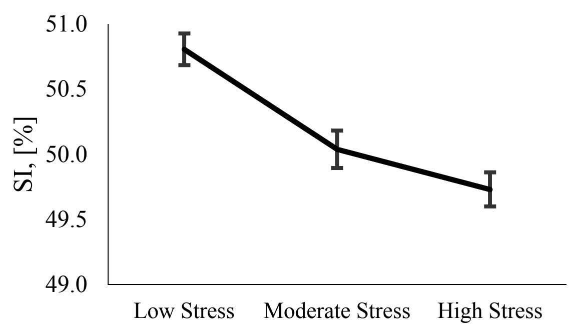
PI: Porta Index, GI: Guzik Index, SI: Slope Index



(a)



(b)



(c)

Figure 1. Porta Index (PI), Guzik Index (GI), and Slope Index (SI) across groups with different stress level (the bars show the standard error).

HRA significantly reduced by stress level ($p<0.05$); on average, 2.1% lower HRA was observed in high stress, compared to moderate stress, and low stress. Further pairwise comparison revealed that PI was significantly different between low and moderate stress ($p=0.004$), as well as moderate and high stress ($p=0.047$). Also, GI and SI were an independent discriminator between low and moderate stress ($p<0.001$), and between low and high stress ($p<0.001$). All HRA indexes showed large effect sizes between low and moderate stress. Furthermore, GI and PI were the only HRA parameters with large effect size between low and high stress. Effect sizes between moderate and high stress were moderate for all HRA indexes. A correlation analysis between HRA indexes revealed a significant very strong correlation between GI and SI ($r= 0.95$, $p<0.001$).

4. Discussion

In this article, HRA as an indicator of imbalance between acceleration and deceleration of heart rate [12, 18], was studied across groups with the different stress level. The results showed a reduction in PI in high stress group compared to low stress group. Also, both GI and SI have shown a trend of reduction from low stress toward moderate and high stress. The reduction in PI in high stress group compared to low stress group is an indicator of increased prevalence of acceleration in high stress situations. Reduction in GI and SI in high stress level compared to moderate and low stress suggests that acceleration is a dominant factor for creating magnitude and phase asymmetry. Both increase in sympathetic and decrease in parasympathetic nervous system activities that occurred in response to stress may lead to heart rate acceleration. Within the above-mentioned results, the physiological stress response (increase in activity of sympathetic nervous system and decrease in activity of parasympathetic nervous system [7-9]) were determined and showed that HRA can effectively represent this response. The high standard error within the PI index suggest a higher variation in groups with different stress level. Therefore, information on prevalence of acceleration and deceleration captured by this index may not be sufficient to capture stress level.

In agreement to our results, Visnocova et al. [22] studied HRA in response to acute mental stress induced in laboratory environment through stroop color and arithmetic tests, and reported a reduction in PI and GI in stressful condition compare to the non-stressful baseline condition. Our results for stress assessment during uncontrolled conditions (i.e., street and highway driving) are in line with results of this study. Furthermore, our results on GI and SI suggest that decrease in HRA indexes with an increase in the level of stress have the potential for multi-level stress assessment. Of note, HRA is a new measure and the impact of various physiological mechanisms on it is still unclear. Therefore, further research is required to clearly understand the relationship between HRA alterations and physiological stress response.

Lack of information about the activity level as a confounding factor and a small sample size are limitations of this study. Nevertheless, the promising results of the current article that shows a reduction in HRA in response to stress warrant future studies on a larger population.

5. Conclusion

Heart rate asymmetry across groups with the different stress levels was studied in this article. This study suggests that assessment of HRA can discriminate different level of stress and has a potential to be used in conjunction with conventional HRV parameters. We speculate that reduction in HRA (dominant of heart rate acceleration compared to decelerations) may be linked to the physiological stress response in more stressful situations.

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