EVALUATION OF STRESS PARAMETERS BASED ON HEART RATE VARIABILITY MEASUREMENTS

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Abstract: *In this study, heart rate variability measurements and analyses were carried out with help of the ECG recordings to show how autonomic nervous system activity changes. ECG signal recording was collected from six volunteer participants under following conditions; the situation of relaxation, Stroop color/word test, mental test and auditory stimulus in a laboratory environment so as to evaluate the parameters related to stress. Totally seven minutes ECG recording was taken and analyzed in time and frequency domain. We investigated that how autonomic nervous system activity changed in the position of stress. According to frequency domain analysis, there has seen significant increase at low frequency band (LF band) which reflects sympathetic activity particularly during Stroop color/word and mental tests.*

Keywords: *Stress, heart rate variability, autonomic nervous system*

1. Introduction

Stress which is a part of daily routine is body's reaction to sensed emotional, mental or physical affliction [1]. Some studies [2, 3] showed that reasonable levels of stress can provide positive effect such as an increment in concentration power. Extreme levels of stress has destructive effects such as cognitive dysfunctions, depression, cardiovascular diseases [4,5] or psychiatric disorders such as anxiety, depression, and Alzheimer [6]. The autonomic nervous system (ANS) which performs dynamically regulation of our body system through sympathetic (crucial in danger situations) and parasympathetic (induces relaxation response) branches is triggered under stress condition. In this situation, parasympathetic nervous system is depressed while sympathetic nervous system is activated. The activation of sympathetic nervous system leads to increase of blood pressure and heart rate [7]. The changes that occur at heart rate are called heart rate variability (HRV). In other words, HRV is time differences between two consecutive R waves [8]. HRV is assessed either by time domain or frequency domain analyses which are including power spectral density analysis. HRV is disposed to be higher and more complex when the ANS is in balance. Otherwise, HRV tends to be lower. This situation can be used for stress evaluation.

Electrocardiogram signal (ECG) is accepted gold standard in HRV analysis [9]. Moreover, ECG signal recording reflects the electrical activity of the heart which is controlled by the ANS.

Numerous studies [9-13] have been performed to understanding and evaluation of stress during the last few decades. HRV which is derived from photopletismograph or electrocardiogram (ECG) signal was analyzed in these studies. HRV analyses which are performed both time and frequency domain are calculated by time differences between consecutive R waves in the ECG signal.

There are various studies [7,8,11,14-16] using different combinations of stress conditions to calculate HRV based on ECG signals under stress and stress free situations. Taelman et al. [7] studied the effect of mental stressor on HRV and reported that a significant difference between the rest and mental task conditions. The relationship between HRV and stress generated by visual stimuli has been investigated. Significant changes in HRV that occurred in the case of visual stress was determined [14,15]. Oh et al. [16] investigated the effects of noisy sounds on human stress by using ECG signals. The results of these signals showed that some of these noisy sounds lead to increase the stress level on humans. Visnovcova et al. [11] observed a reduction of HRV complexity under two different stress situations (Stroop test, mental arithmetic) with regard to the baseline. A large part of studies demonstrated that standard deviation of all NN interval (SDNN) and high frequency band (HF) decreased whereas LF and LF/HF increased during stress situations [8].

The main purpose of this study is to examine whether there is a relationship between stress and HRV parameters which are derived from ECG signals and determine the

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effect of stress on ANS activity. We also investigated how auditory stimulus has an effect on the ANS activity.

The remainder of this paper is organized as follows: data collection, experimental protocol and signal analysis are explained in Section 2. In Section 3 and Section 4, calculated HRV parameters and discussion are ensured respectively. Finally, conclusion is presented in Section 5.

2. Method

2.1. Participants

A total of 6 volunteer participants 2 of female and 4 of male with mean age of 27 (±3.87) took part in our experimental study. All participants were asked to drink tea, coffee, alcohol, etc. which affect the cardiovascular system for three hours before the experiment. None of the subjects had no history of cardiovascular disease and psychiatric condition.

2.2. Data Collection

ECG signals were acquired by using Biopac MP36 unit at a sampling rate of 1000 Hz sampling frequency. The subjects sat on a comfortable chair and were verbally informed about the aim and procedure of this study. For ECG signal recording, Ag/AgCl electrodes were placed at subject's right forearm (negative), left leg (positive) and right leg (ground) to make possible recording of Lead II trace. ECG signal recording was performed in the following situations: baseline (S1), Stroop color/word test (S2), post-stress recovery (S3), mental test (S4), recovery (S5), auditory stimulus (S6), recovery (S7). We aimed to induce stress at the subject using Stroop color/word test, mental test and auditory stimulus situations. To be able to make an equitable comparison, each task session had a same duration of one minute. The procedure for the experiment is shown in Fig.1.

Firstly, one minute signal was received from each participant and this signal was accepted baseline. ECG signal was collected without any stimulus for one minute in this part. After this section, various tests are applied to induce stress at the subject.

2.3 Stress Conditions

2.3.1. Stroop Color/Word Test

Stroop color/word test [17] is a cognitive test which was carried out by J.R. Stroop in 1953. The test consists of three parts, but only the third part has been applied to the participants. Participants are asked to read the words written in different colors from the color name printed on the paper as quickly as possible. The result is known as Stroop effect that subjects are forced to read color names written in different color.

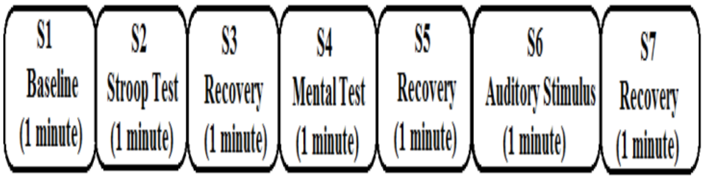

Fig. 1. Procedure of the experiment

Stroop color/word test was applied to the subjects for one minute. After that recovery session (S3) was performed for heart rate stabilization and rest after stress. Fig. 2 shows a part of the Stroop color/word test.

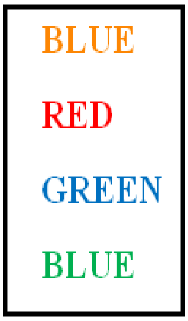

Fig. 2. A part of Stroop color/word test

2.3.2 Mental Test

Mental arithmetic test is one of the methods frequently used in the literature to induce stress [9, 11, 18, 19]. Participants were asked to perform arithmetic task for 1 minute. Briefly, subjects started to subtract 7 then subtract 7 and so on, starting from 3000 as quickly as possible. Results showed that all participants were stressed in this section.

2.3.3 Auditory Stimulation

Auditory stimulus can be used as stress inducer [16]. In this section participants were exposed to tension musics for 1 minute via an earphone with their eyes closed. It has been said that at any moment a needle immersed in order to increase the stress level of participants.

2.4 Signal Analysis

After ECG recordings were taken the signal was filtered to remove noise and baseline drift before HRV analysis. Firstly, moving average filter was used to eliminate noise for filtering after that a high pass FIR filter with a 0.5 Hz cut of frequency was used to remove baseline drift. Lastly notch filter was applied to eliminate 50 Hz power line interference.

Fig. 3 shows flowchart which is representing the process steps for HRV analysis. Baseline shift in the signal was removed after filtering and noise was eliminated as shown in Fig. 4.

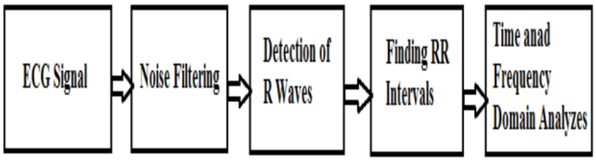

Fig. 3. Process steps for ECG Signal Analysis

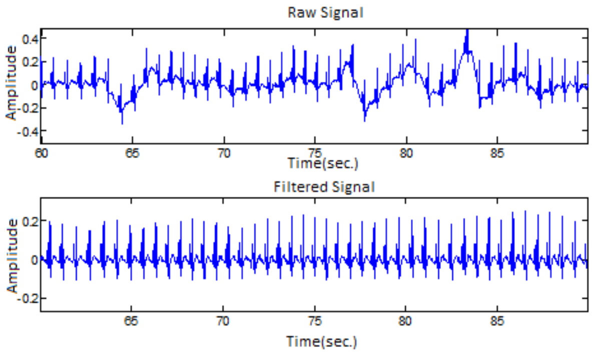

Fig. 4. Raw and filtered ECG signal

R wave detection in the ECG signal was performed by using the Pan Tompkins algorithm [20] as shown in Fig. 5. Successful inter-beat intervals (between two R waves) are calculated by using HRV analyses and these analyses are carried out in two steps which are time and frequency domain analyses.

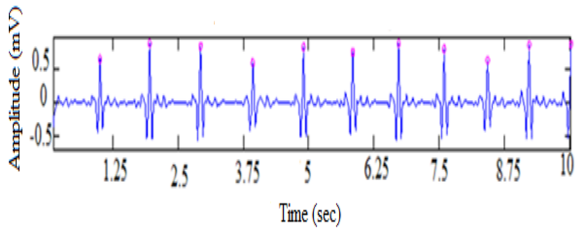

Fig. 5. R wave detected signal

Measurement standards which are recommended by the European Society of Cardiology and North American Society of Pacing and Electrophysiology guidelines (ESC / NASPE) are accepted for HRV analyses [21]. Some significant time and frequency domain parameters and descriptions are shown in Table 1. As seen in Table 1 time domain measurements include the mean of RR intervals (Mean RR), standard deviation of normal normal intervals (SDNN), the square root of mean squared difference of successive RR's (RMSSD) and percentage of normal normal intervals that vary by more than 50 milliseconds from the previous interval (PNN50). Frequency domain HRV measurements contain very low frequency power (VLF), low frequency power (LF), high frequency power (HF) and LF/HF. There is a need for time series which are calculated from the consecutive RR intervals, in the time domain measurements. Frequency domain measurements and power spectral density (PSD) are calculated by using fast Fourier transformation. Time domain methods are very simple to calculate because they are implemented directly to the series of consecutive RR interval values. However, these measurements do not provide information on the amount of autonomic balance or the temporal distribution of the power different branches of the ANS. The amount of autonomic balance can be determined at any given time with frequency domain methods.

Table 1. Time and frequency domain parameters for HRV analyses

Variable	Unit	Description
Time Domain Parameters		
Mean RR	ms	Average RR interval
SDNN	ms	Standard deviation of all NN interval
RMSSD	ms	The square root of the mean squared difference between adjacent N-N intervals, reflects mainly vagally influence
pNN50	%	Percentage of normal normal intervals greater than 50 milliseconds
Frequency Domain Parameters		
VLF	ms^2	Power spectrum band between 0.003-0.04 Hz
LF	ms^2	Power spectrum band between 0.04-0.15 Hz, reflects sympathetic activity
HF	ms^2	Power spectrum band between 0.15-0.4 Hz, reflects parasympathetic activity
LF/HF	n.u.	Reflects sympathovagal balance

3. Results

In this study, ECG signals during seven minutes received from volunteer participants under different test procedures were analyzed. The first minute of these signals was accepted as the reference (baseline). Results were interpreted by comparing the change of parameters in the stress condition with this reference signal.

The comparisons of HRV parameters under different conditions with mean and standard deviation values are shown in Table 2.(a) and 2.(b). The time and frequency domain parameters given in tables are the most commonly used parameters for measuring and evaluating stress in the literature. As shown in Table 2.(a) the mean value of RR intervals was 737.4±91.1 during the rest state, it considerably decreased 691±47,8 in Stroop color/word test and 686.2±64.9 in mental task. There was an important distinction between these situations and these values show that when the person feels under stress heart rate accelerates. Significant changes were observed in LF band which is reflecting sympathetic activity. LF power is 427.8±442.3 at the baseline level, while the power at this band in the Stroop and mental test is 813.4±1154 and 1432±1029 respectively. A significant increase in sympathetic activity has occured as expected in stress situations. Appropriately, the ratio of between LF and HF power which is reflecting sympathovagal balance increased due to the increase in LF power during Stroop and mental test. The auditory stimulus that leads to a person's tension state does not seem to cause a significant change in the level of stress of the person.

Result of the analysis on the frequency domain belongs to one of the participants is seen in Fig. 6. Figure 6.a and 6.b demonstrate power spectral density graphs of the person's resting state and mental test respectively. While the power of the LF band is 580.1 ms^2 and the power of the HF band is 451.4 ms^2 in resting state, the power of the LF band increased to 1945.4 ms^2 and the power of the HF band decreased to 91.2 ms^2 during the mental test. Sympathetic activity and the power of the LF band reflecting the sympathetic activity increased during the mental test.

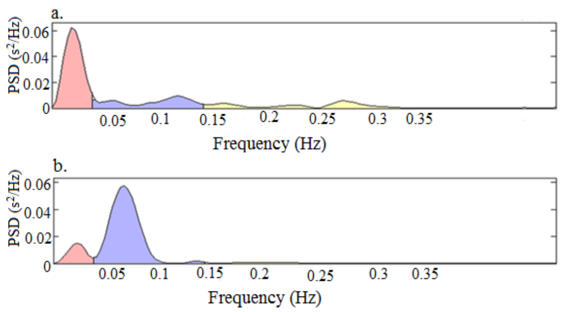

Fig. 6. Power spectral density graph of a participant during rest state (a) and mental test (b). (Variance is indicated s^2)

How Mean Normalized RR intervals of the participants have changed during resting state, Stroop color/word test, mental test and auditory stimulus is depicted in Fig. 7. A significant difference was not observed between the baseline and the auditory stimulus condition, whereas there was a decrease in average RR interval in almost all participants during the Stroop color / word and mental test.

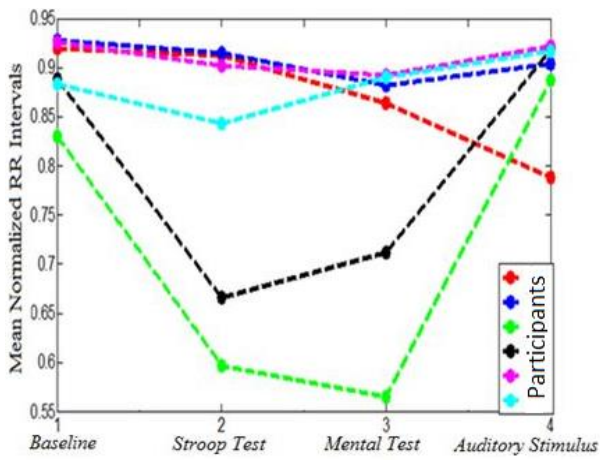

Fig. 7. Mean Normalized RR interval change in baseline, stroop test, mental activity and auditory stimulus states belong to 6 participants

Table 2.(a) Mean ± standard deviation values of time domain parameters under different conditions

	Mean RR	SDNN	RMSSD	PNN50	Mean HR
Baseline (S1)	737,4± 91,1	33,1± 11,1	20± 9,9	4,7± 6,4	82,5± 9,2
Stroop color/ word test (S2)	691± 47,8	37,8± 19	22± 13,5	6,6± 9,8	87,4± 5,6
Recovery (S3)	751,12± 78,7	45,3± 22,1	26,8± 14,3	7,6± 6,5	81± 7,8
Mental test (S4)	686,2± 64,9	45,7± 13,9	25,14± 12,2	8,4± 9,9	88,4± 7,4
Recovery (S5)	742,6± 66	53,67± 31	41,67± 27	9,05± 9,9	81,7± 6,7
Auditory stimulus (S6)	753,7± 102	29,7± 9,5	25,5± 11,4	6,2± 8,9	80,9± 10
Recovery (S7)	740± 68,8	42,1± 12,5	26,8± 10,5	6,3± 7	81,9± 7,1

Table 2.(b) Mean ± standard deviation values of frequency domain parameters under different conditions

	LF	HF	LF/HF
Baseline (S1)	427,8±442,3	271,8±275	1,8±1
Stroop color/word test (S2)	813,4±1154	287,4±275	3,7±3,4
Recovery (S3)	972±1377	312±374	3,5±4,7
Mental test (S4)	1432,8±1029	381±322	6,7±7,6
Recovery (S5)	1385±2200	538,4±768	2,7±2,27
Auditory stimulus (S6)	349±278,8	179±162,7	2,76±2,3
Recovery (S7)	836±675	295±255	7,9±11,1

4. Discussion

The present study explored the effect of different stressors (Stroop color/word test, mental test and auditory stimulus) on ANS activity by using HRV time and frequency domain analyses. We assessed the HRV parameters acquisition from ECG signal recording for two conditions: rest and different stress situations. According to the results obtained from study, a significant decrease was observed in the average RR interval in Stroop color/word and mental test. Mean heart rate (mean HR), SDNN and pNN50 values calculated by using time domain measurements increased during the Stroop color/word and mental test, these findings support the results in [19]. Unlike Stroop color/word and mental test there is no significant change in the auditory stimulus state. This finding demonstrates that the auditory stimulus does not cause a situation that would stress someone out. It was also observed that the meaningful changes in time and frequency domain occur in the recovery (S7), immediately after the auditory stimulus, rather than in the auditory stimulus (S6). A considerable increase was observed in the LF band reflecting the sympathetic activity during the Stroop color/word and mental test, when compared with resting state. However, unlike [9, 11] there is no significant difference in the HF power between rest and stress conditions except auditory stimulus situation. A slight decrease was detected in the HF band only in the case of auditory stimulus. These differences between rest and different stress conditions are expected and results are in agreement with the other studies [8].

5. Conclusion

In this study we demonstrated clearly that HRV is a very useful tool to show how ANS activity changes under stress condition. We investigated HRV characteristics for rest and three different stress situations which are Stroop color/word test, mental test and auditory stimulus. According to time and frequency domain analyses some significant differences were observed between rest and stress conditions. From HRV data presented here, we conclude that under stress situation there was an increase in LF power which reflects sympathetic activity whereas a decrease in the HF band which reflects parasympathetic activity.

The system design will be performed by us to collect data besides this, the results will be made more general with the use of statistical analysis methods in future work of the study.

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