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Mental Stress Evaluation using Heart Rate Variability Analysis: A Review

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Abstract: **In this paper we reviewed Heart Rate Variability (HRV) analysis in evaluation of mental stress. Over the years many researchers have contributed in estimating relation between HRV and Perceived Mental Stress. In this article we analyzed various techniques available for evaluation of mental stress. Time domain and frequency domain analysis results are reviewed for understanding the significance of HRV. Various instruments developed have been reviewed and analyzed their effectiveness. Results of two case studies performed in two different environments for establishing relation between HRV and perceived mental stress have been discussed.**

Key words **— mental stress, heart rate, heart rate variability**

I. INTRODUCTION

Mental Stress is a normal physical response to environmental condition or a stimulus or events that make person feel threatened or upset. Sympathetic nervous system responds to stress. Due to the response of body during stress physiological parameters of the body are affected. Attempt to identify the effect of mental stress on Heart Rate is analyzed. Many methods have been developed for studying effect of perceived mental stress on Heart Rate. Different research have shown that Heart Rate Variability can be significant parameter in analyzing mental stress. This leads us to study the relation between HRV & mental stress, different existing techniques and study developed instruments.

II. TECHNIQUES AVAILABLE FOR EVALUATION OF MENTAL STRESS

EEG, GSR, Salivary Cortisol, HRV, Pupil Diameter (PD), Finger Temperature (FT), plethysmography, Sweat Electrolyte Quantity, Systolic Blood Pressure, Glucose level, Body Temperature are some factors by which stress can be evaluated.

Mental Stress Evaluation from EEG: The method involves the correlation between EEG power spectra in each frequency bands to the mental/cognitive state. According to the frontal asymmetry proposal it has been said that the ratio between alpha and beta ratio in left and right hemisphere can be used to indicate the existence of stress. A non-invasive technique having frequency of alpha waves within the ranges of 8-13 Hz are associated with relaxation while Beta waves varying from 14-30 Hz are associated with active thinking, active attention, focus, etc.

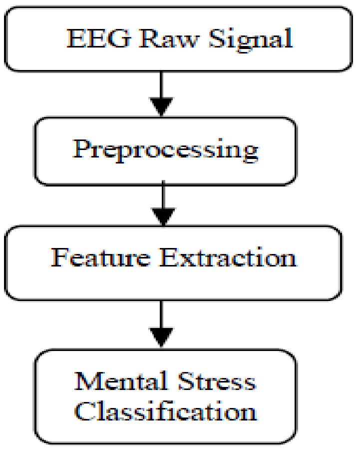

Fig. 1. Human stress measure using EEG Signals [5]

Stress evaluation from Galvanic Skin response and PD: Galvanic Skin Response (GSR) and Pupil Diameter (PD) can be used to monitor the stress state using a computer game named the 'Stroop Test'. Results conclude that human Autonomic Nervous System (ANS) ascendance GSR and PD and hence mental state of stress can be evaluated.

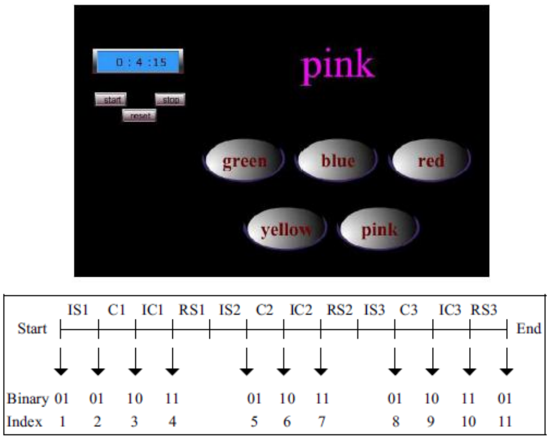

Fig.2. Sample Stroop Test interface [2]

Continuous measurement of sweat electrolyte quantity to Evaluate mental stress: As mental stress leads to sweating on palms; so, concentration of electrolytes contained in sweat undergoes noticeable change. Quantity of sweat was being measured by a pure-water-perfusing chamber.

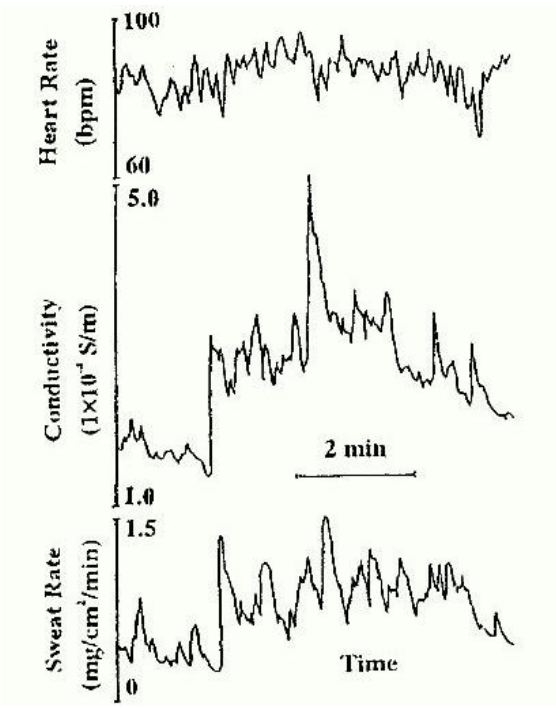

Fig. 3. Result of the simultaneous measurement of sweat rate, seat conductivity and heart rate

Plethysmography for the evaluation of mental stress: Continuous wavelet Transform of PPG signal has been done to measure the mental stress. A stress parameter was used having significance value of 0.002. On the basis of that parameter the increased or decreased mental stress was evaluated.

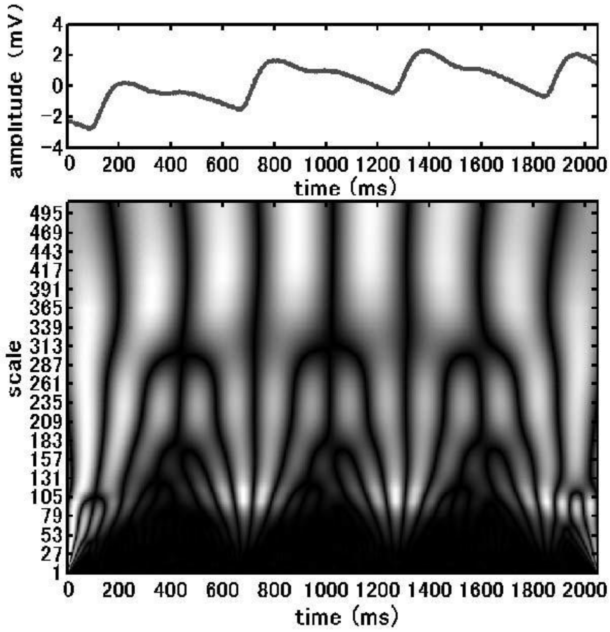

Fig.4. Continuous wavelet Transform of PPG signal and stress scale [3]

Measurement of mental stress using HRV: The autonomic nervous system (ANS), which is sympathetic and parasympathetic in nature; keep a check on cardiac muscles. Mental stress is influenced by dynamic changes in autonomic nervous system (ANS) activity. Hence, HRV evaluated from ECG can be used to measure the stress. Variability in inter beat interval (IBI) is HRV and explained as the time in milliseconds between two consecutive R waves of an ECG.

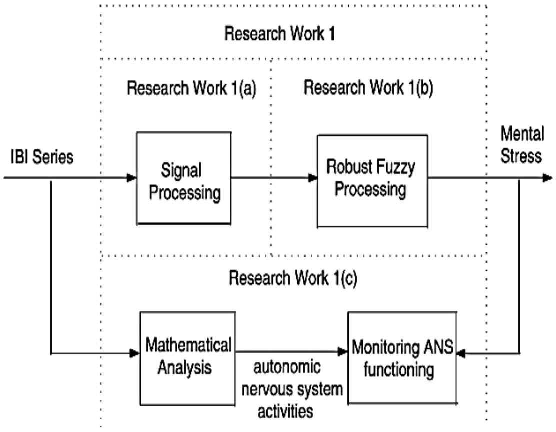

Fig. 5. Process of calculating stress from HRV [4]

Mental Stress induced Changes in Cortisol Levels: Change in the values of salivary cortisol leads us to develop a strong modus for stress measurement. Stress-induced hemodynamic changes are fragile to photoplethysmogram which can help us to estimate stress for subjective cases as shown in Table 1.

Stressful Conditions	Before Test	After Test	t Value
Negative Pictures	3.423 ± 1.906	3.967 ± 2.223	2.62*
Neutral Pictures	3.546 ± 2.282	3.498 ± 2.207	0.67

n=55, mean ± SD, * P<0.05

Table.1. Salivary cortisol levels before and after the test [7]

III. SIGNIFICANCE OF HEART RATE VARIABILITY IN EVALUATION OF MENTAL STRESS

There are two main methods of HRV analysis: time domain and frequency domain. [9][10]

1. *Time Domain Analysis:* This method involves direct usage of time domain analysis of RR interval signals. It includes methods such as mean heart rate (mHR), mean RR interval (mRR), standard deviation of RR interval (SDRR), standard deviation of heart rate (SDRR), coefficient of variance of RR interval (CVRR), root mean square successive difference (RMSSD), number of pairs of adjacent RR intervals differing by more than 20 ms to all RR intervals (pRR20) and number of pairs of adjacent RR intervals differing by more than 50 ms to all RR intervals (pRR50). They can be calculated as per the below formula as shown in Table 2.

No	Measure	Unit	Formula
1	*mRR*	ms	$\frac{\sum_{i=1}^{N}(RR_i)}{N}$
2	*mHR*	bpm	$\frac{\sum_{i=1}^{N}(60000/RR_i)}{N}$
3	*SDRR*	ms	$sqrt\left(\frac{\sum_{i=1}^{N}(RR_i - mRR)^2}{N-1}\right)$
4	*SDHR*	bpm	$sqrt\left(\frac{\sum_{i=1}^{N}((60000/RR_i) - mHR)^2}{N-1}\right)$
5	*CVRR*		$\frac{SDRR \times 100}{mRR}$
6	*RMSSD*	ms	$sqrt\left(mean\left(\left(RR_{i+1} - RR_i\right)^2\right)\right)$
7	*pRR20*	%	$\frac{Count\left(\left\lvert RR_{i+1} - RR_i \right\rvert\right)_{>20ms} \times 100}{N-1}$
8	*pRR50*	%	$\frac{Count\left(\left\lvert RR_{i+1} - RR_i \right\rvert\right)_{>50ms} \times 100}{N-1}$

Table 2. HRV measures in Time Domain [9]

The most prominent measures for HRV in time domain is mRR. A low mRR value indicates condition of stress.

2. *Frequency Domain Analysis*: It involves power spectral density computation of RR interval by means of Fourier transform. It includes power spectrum of very low frequency (VLF), of low frequency (LF) and of high frequency(HF), normalized very low frequency spectrum (nVLF), normalized low frequency spectrum (nLF), normalized high frequency spectrum (nHF), difference of normalized low frequency spectrum and normalized high frequency spectrum (dLFHF), Sympathetic modulation index(SMI), Vagal modulation

index(VMI) and Symphatovagal balance index (SVI). They can be calculated as per the below formula as shown in Table 3.

No	Measure	Unit	Description
1	*VLF*	ms^2	Power spectrum from 0.003 to 0.04 Hz
2	*LF*	ms^2	Power spectrum from 0.04 to 0.15 Hz
3	*HF*	ms^2	Power spectrum from 0.15 to 0.4 Hz
4	*nVLF*	%	$VLF \times 100 / (VLF+LF+HF)$
5	*nLF*	%	$LF \times 100 / (VLF+LF+HF)$
6	*nHF*	%	$HF \times 100 / (VLF+LF+HF)$
7	*dLFHF*	%	$\lvert nLF - nHF \rvert$
8	*SMI*		$LF/(LF+HF)$
9	*VMI*		$HF/(LF+HF)$
10	*SVI*		LF/HF

Table 3. HRV measures in Frequency domain [9]

The most prominent measures for HRV in frequency domain is LF/HF. A high LF/HF value indicates condition of stress. [11]

IV. INSTRUMENTS DEVELOPED SO FAR FOR MENTAL STRESS EVALUATION FROM HRV

In 1998, Wang, F., K. Sagawa, and H. Inooka introduced a new simple time domain HRV index for the assessment if dynamic change of stress like in the case of exercise, where the heart rate changes rapidly over time, making frequency domain analysis of HRV unsuitable.[12]

In 1998, Colombo, R., et al. designed a computerized system that was able to carry out complete spectral analysis of HRV signal. The ECG, blood pressure, and respiratory signal were acquired and processed using FFT and simultaneously an autoregressive identification algorithm was also carried to calculate the power and central frequency of the spectra peaks. [13]

In 2007, Kumar, Mohit, et al. presented a novel technique HRV analysis for mental stress assessment using fuzzy clustering and robust identification techniques. In this approach the heart rate signals were monitored online and then processed using continuous wavelet transform. Fuzzy clustering methods have been used to model the experimental data. Further, a robust fuzzy identification technique has been used to handle the uncertainties due to individual variations for the assessment of mental stress. [14]

In 2008, Kim, Desok, et al. investigated time dependent variations of HRV features to detect subjects under chronic mental stress. HRV features were calculated during three different time periods of the day. An accuracy of 63.2% was obtained, when logistic regression analysis was performed with raw multiple HRV features. [15]

In 2009, Nagae, Daisuke, and A. Mase. proposed a new method of stress evaluation where the heart beat was measured using a microwave reflectometer and the stress-analysis algorithm was used to calculate the LF/HF ratio by applying optimum signal processing to the reflectometer signals as the ECG method is not good for long term monitoring since several electrode had to be attached to body to acquire the signal. [16]

In 2010, Wu, Wanqing, and Jungtae Lee. developed a multi-channel portable ECG device for signal collection, and then they designed full-featured ECG monitoring system which suitable for real-time ECG display, signal processing, high accuracy R wave detection and HRV analysis in time and frequency domain. [17]

Again in 2010, Nagae, Daisuke, and Atsushi Mase presented two robust signal processing techniques for stress evaluation using a microwave reflectometric cardiopulmonary sensing instrument. These techniques enable the heart rate variability (HRV) to be recovered from measurements of body-surface dynamic motion, which is subsequently used for the stress evaluation. Two novel elements, one is the reconfiguration of the HRV from the cross-correlation function between a measurement signal and a template signal which is constructed by averaging periodic component over a measurement time. The other is a reconstruction of the HRV from the time variation of the heartbeat frequency; this is evaluated by a repetition of the maximum entropy method. [18]

In 2011, Boonnithi, Sansanee, and Sukanya Phongsuphap investigated various heart rate variability (HRV) measures for detecting mental stress by using ultra short term HRV analysis. A number of HRV measures were investigated, e.g., Mean of heart rates (mHR), Mean of RR intervals (mRR), Power spectra in Very Low (VLF), Low (LF), and High (HF) frequency ranges, Symphatovagal balance index (SVI), etc.[9]

In 2012, Costin, R., Cristian Rotariu, and A. Pasarica investigated objective characteristics, like various short term heart rate variability (HRV) measures and morphologic variability (MV) of ECG signals for detecting mental stress. A number of HRV measures were investigated, both in time domain and frequency domain. [10]

In 2014, D'addio, G., et al. developed a nonlinear measures of HRV during ECG stress test based on typical properties of chaotic systems and deterministic fractal. A fractal analysis by Higuchi's algorithm (FD) has been performed on 26 cardiac patients during resting, stress, early and late recovery phases of ECG stress test. Results showed a significant FD increasing values from resting to stress phase that was not recovered at all immediately after the exercise, and it was slightly recovered both during early and late recovery phase. The performance of fractal analysis of HRV during and after high intensity exercise suggests that it could be a useful index assessing relevant information about underlying physiological recovery. [19]

V. CASE STUDIES

Case study 1: The first case we studied was that of Katholieke Universiteit Leuven.[11] The experiment was carried out on 15 men and 13 women with mean age of 22 (±1.96) and average body mass index of 22.2 (±0.43). Readings were taken for two conditions, the first when the patients were at rest and the second one when they were performing a mental task. For both these conditions, average heart beat period (Mean RR (in ms)) was calculated. Similarly, in frequency domain, LF and HF component was determined for each subject in each condition and then LF/HF ratio was calculated as shown in following Table 4.

	Rest	Mental task
Mean RR (ms)	0.816 (±0.13)	0.790 (±0.13)
Mean LF/HF	2.55(±1.94)	3.14(±2.68)

Table 4. [11]

Case study 2: In Second Case study conducted by Reeta Orsila, Matti Virtanen in which perceived mental stress is compared to HRV during occupational work. Traditional questionnaire and wristop heart rate monitor along with related software was used. Useful HRV parameters for detecting mental stress were identified. Results shown that highest correlation between perceived mental stress with the differences between the values of triangular interpolation of rythm-to-rythm (RR) interval histogram (TINN) and the root mean square of differences of successive RR intervals (RMSSD) obtained in the morning and during the workday (r = –.73 and r = –.60, respectively). From analysis of the result obtained in this case study it was found that RMSSD and TINN value differences increase from night to morning, the stress decreases.[20] Graph of both these parameters shown in Fig 6 and Fig 7 respectively.

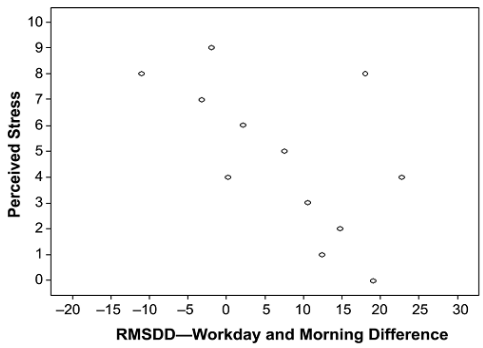

Fig 6. [20]

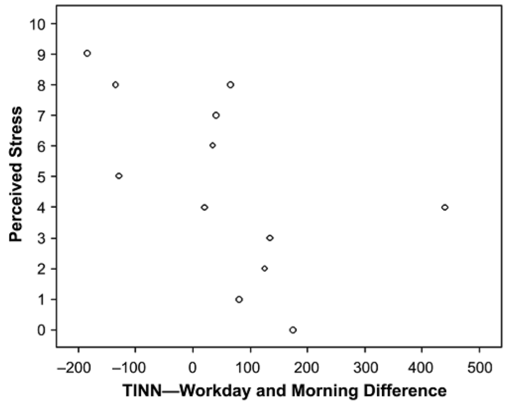

Fig 7. [20]

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