HEART RATE VARIABILITY DERIVED FROM WRIST PHOTOPLETHYSMOGRAPHY SENSOR FOR MENTAL STRESS ASSESSMENT

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Abstract: Generally, mental illness is an abstract condition that is difficult to be measured. However, there is a strong relation of human mental state with several physiological processes in the human body such as changes in heart rate variability (HRV). HRV has the potential to provide additional valuable insight into physiological and pathological condition of human heart. In clinical basis, ECG has been used for years to measure HRV for stress assessment. However, this technique causes slight discomfort to the patients and is inconvenient for application in long-term stress monitoring device. The introduction of pulse rate monitor allows easy monitoring of these parameters but its accuracy and reliability are still uncertain. This study aimed to study the relation of HRV feature with mental stress by using photoplethysmograph (PPG). The PPG signals were collected from 12 healthy adults during resting and arithmetic stress test by using both PPG and ECG. HRV features were then extracted using time-domain analysis (TA), frequency-domain analysis (FA) and non-linear time-frequency analysis (TFA). From the results, it can be seen that most HRV features extracted using PPG showed significant correlation ($p < 0.01$) between HRV features extracted from ECG. This concludes that, PPG can be used as an alternative tool to measure the HRV during mental stress test as it is much more convenient for stress assessment yet performs as an accurate measure.

Keywords: PPG, stress, HRV, ECG

1. Introduction

Mental health is equivalently important as physical abilities to one’s wellbeing and quality of life. A state of mental instability would detrimentally affect proper functioning of the biological systems in the body. The biggest threat to mental health is stress. Stress can be interpreted as residual feelings and memories from specific life events that are perceived as traumatizing. Withdrawal from stressful experience may pushes the individual into a state of avoidance or denial. This issue is very concerning because mental stress has a way of effecting not only psychological stability of the diseased but also their physiological health.

Based on many studies and retrospective records, it was observed that individuals under stress are more likely associated with severe progression of clinical depression, cardiovascular diseases (CVD), human immunodeficiency virus (HIV), and cancer [1]. Due to this matter, it is obvious that adequate interventions should be taken in identifying individuals who are suffering severe stress conditions so that appropriate treatment and action can be given in a timely manner. There are many methods available to determine the mental health and stress level of a person such as stress scale questionnaires and salivary cortisol test.

Recently, measurement of heart rate variability (HRV) parameters has also been used clinically for stress test [2]. Variation in HRV parameters reflects the level of stress experienced by different individual [3,4]. Methods such as electrocardiograph (ECG) and photoplethysmography (PPG) can be used to quantify HRV parameters. PPG provides an alternative to standard ECG in measuring HRV as it is simple, light-weighted and wearable, and able for application at the peripheral position [5]. HRV parameters obtained through PPG has shown positive correlation with the measurement taken through ECG [6]. Although, these PPG system has shown great performance so far, more studies are being done to determine the validity and stability of this system to provide accurate extraction of HRV features.

Many studies utilizing ECG for quantifying level of mental stress has proven that several HRV features has significantly changed under stressful conditions [7,8]. Short-term HRV analysis has garnered attention as it able to provide immediate test results which makes it applicable for wearable monitoring device, remote patient care and in applications where results are immediately required. Thus, the combination of both short-term HRV analysis into PPG system may expedite the functionality and robustness of PPG device as a diagnostic and monitoring tool.

This study will investigate the effectiveness of PPG as an alternative method to measure the HRV features under short term analysis and perhaps provide a more convenient yet accurate measurement for stress assessment.

2. Method

2.1 1.1 Data Acquisition

A total of 12 healthy subjects with no prior symptoms of autonomic or cardiovascular disorder participated in the study. The subjects were randomly selected students in Universiti Teknologi Malaysia that ages between 20 to 30 years old. For the evaluation of HRV under stress conditions, subjects were required to perform an online arithmetic test for 10 minutes as a form of mental stress test. The arithmetic test comprises of simple addition, subtraction, multiplication and division questions with random values generated between single to three digit numbers. Each subjects were instructed to answer as much questions possible within the time limit and next questions would only appear when correct answer was given.

The signal recording is performed simultaneously using ECG and PPG device. The ECG recording was conducted using three lead system, disposable solid gel electrodes were attached on the chest, under right clavicle (‘Negative’), under left clavicle (‘Ground’) and lower left ribcage (‘Positive’) to enable recording of the Lead II trace. PPG signals were recorded using a pulse sensor attached to the wrist and connected to a computer that visualize and store the signals. Both signals were collected over cumulative duration of 30 minutes which comprised of 10 minutes adaptation time, 10 minutes resting (baseline) condition and 10 minutes under mental arithmetic test (Figure 3.2).

2.2 Signal Pre-processing

A preliminary signal processing stage was implemented on the recorded ECG and PPG signals using MATLAB software before HRV quantification was done. The QRS peaks in ECG signal were detected using Pan and Tompkins algorithm as it is able to produce high precision of peak detection rate in adults [9]. The HRV from PPG signals were extracted using the slope sum function (SSF) algorithm proposed in Jang et. al [10].

The preliminary step needed to acquire HRV was introducing digital bandpass filter to attenuate noises contained in the signals. The bandpass filter consisted of consequent lowpass and highpass filters, with cut-off frequencies of 5 and 11 Hz. The lowpass filter (LPF) is applied to remove noises such as EMG from muscle contractions and powerline interference at 50Hz. The high pass filter (HPF) is required to enhance the QRS and pulse peaks while reducing the effect from motion artifacts and other unnecessary frequency components.

2.3 HRV Feature Extraction

The following HRV features (Table 1) were computed based on the guidelines provided by Task Force of The European Society of Cardiology (ESC) [11].

Table 1. Selected HRV features for extraction.

Processing Method	HRV Features	No. of Features
Time Analysis	HR, SDNN, SDANN, RMSSD, HTI, NN50, pNN50	7
Frequency Analysis	VLF, LF, HF, LF/HF, LFnu, HFnu, TP	7
Non-linear Analysis	Shanon Entropy : LF, HF, LF/HF, Total(O) Renyi Entropy : LF, HF, LF/HF, Total(O)	8
	Total	22

3. Result and Discussion

The HRV signal obtained under resting and stress conditions were subsequently plotted in Fig. 1 which also showed the variation between HRV obtained with different time excerpts, varying between 1 and 10 minutes duration. Different lengths of HRV excerpts carry different weightage of information on the HRV of the sample. Longer HRV excerpts allow better visualization of fluctuations in the HRV measurements in both conditions. However, it is difficult to distinguish the difference of HRV changes between resting and stress testing through visual inspection only.

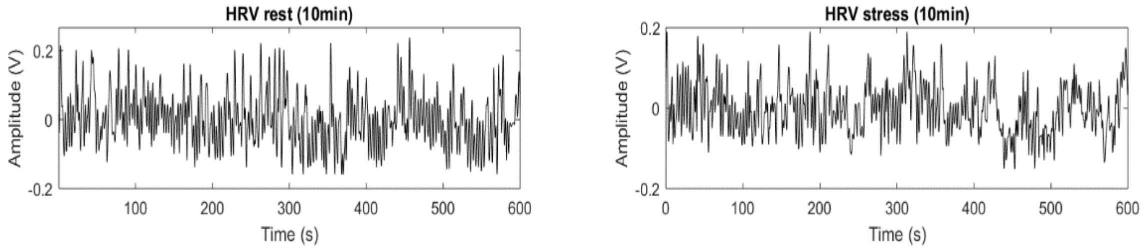

Fig. 1. Samples of PPG-derived HRV for 10 minutes from same sample between resting and stress condition

Correlation analysis was conducted to evaluate the interdependence between PPG-derived HRV and ECG-derived HRV as shown in Table 2.

Table 2. Correlation between multi-length HRV features with standard of 10 minute.

	Features	*r* Rest	*r* Stress
Time Analysis	HR*	**0.964**	**0.970**
	SDNN*	**0.893**	**0.920**
	RMSSD*	**0.793**	**0.801**
	SDANN*	**0.909**	**0.964**
	NN50*	**0.659**	**0.907**
	pNN50*	**0.716**	**0.851**
	HTI*	**0.800**	**0.773**
Frequency Analysis	VLF	**0.918**	0.491
	LF*	**0.773**	**0.764**
	HF*	**0.845**	**0.718**
	LF/HF*	**0.936**	**0.873**
	TP	**0.827**	0.364
	LFnu*	**0.936**	**0.873**
	HFnu*	**0.936**	**0.864**
Non-linear Analysis	ShEn LF*	**0.800**	**0.818**
	ShEn HF*	**0.645**	**0.836**
	ShEn LFHF*	**0.727**	**0.818**
	ShEn O*	**0.709**	**0.773**
	ReEn LF	-0.064	0.255
	ReEn HF*	**0.873**	**0.909**
	ReEn LFHF*	**0.873**	**0.791**
	ReEn O*	**0.909**	**0.945**

In bold Spearman's correlation coefficient (rho) greater than 0.6 and resulted correlation significant (prho < 0.05); *Correlation is significant at the 0.01 level (2-tailed).

HR= Mean of heart rate
SDNN= Standard deviation of NN intervals
RMSSD = Root Mean Square of the Successive Differences
SDANN =Standard deviation of average NN intervals
NN50 = NN intervals differing by more than 50 ms
pNN50 = Percentage of NN50 count
HTI = HRV triangular index
VLF = Very low frequency
LF= Low frequency
HF = High frequency
TP = Total power
LFnu = Low frequency normalized unit
HFnu =High frequency normalized unit
ShEn LF = Shanon Entropy measurements
ReEn =Renyi Entropy measurements

4. Conclusion

For this study, it was assumed that an ultra-short and short-term HRV feature was a valid surrogate of the equivalent standard HRV if the feature maintained a high correlation (i.e. rho> 0.6 and prho < 0.05) with the equivalent standard 5-min feature, over all of the time scales and produce consistent trend and significant difference (p-value < 0.05) during resting and stressing phase. Therefore, it can be deduced that HR, RMSSD, LF/HF, LFnu and HFnu features showed consistent characteristics as valid surrogate of the standard HRV which means regardless of length of HRV signal (between 1 and 10 minutes), these features would produce values that high correlate to value produced with standard HRV excerpt.

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