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Photoplethysmography Based Mental Stress Analysis Algorithm and System for Human Wellbeing Life

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Abstract: HRV, physiological indicators, using the PPG data was found to be changed by mental stress. Our results indicate that PPG measurement may be one of the easiest ways to assess the mental stress quantitatively. In a subsequent experiment, it is necessary to find out the relationship between the physiological indicators and various types of psychological stress.

Keywords: PPG, Mobile sensor, Wellness, Mental stress, Big data, u-healthcare.

1. Introduction

In recent modern society, the incidences of depression and other stress-related diseases are increasing. Mental stress acts as a risk factor affecting a variety of other diseases. A high degree of mental stress contributes to coronary heart disease and cardiovascular diseases such as myocardial ischemia. Identification of individual stress level is the basic step for the prevention of stress-related diseases. A number of studies measuring the mental stress by using a biomarker like salivary cortisol and alpha-amylase have been conducted, but these studies are expensive and require specialized knowledge. Thus, obtaining fast results in mental stress quantitative evaluation at a low cost and using a non-invasive method was considered to be an important goal.

PPG is the equipment which measures the amount of peripheral blood flow, depending on the absorption and reflectivity of the blood vessel using infrared rays. Peripheral blood flow changes in accordance with the autonomic nervous system activity which is known as an indicator of mental stress. Indicators of autonomic nervous system activity are mostly calculated by using the Heart Rate Variability (HRV). In several recent reports, it is reported that HRV in peripheral blood flow and near the heart are the same in physiological function. In HRV measurements, the electrodes typically need to be attached to the chest or abdomen area. On the other hand, PPG minimizes the pressure on the users putting a finger in the device, and it accurately measures the changes in peripheral blood flow. Therefore PPG measurement is non-invasive and the simplest method to measure stress. In addition, it has been suggested that PPG waveform reflects the health condition as indicated by simple and weak signals which is a result of disease or aging. Severe mental stress leads to peripheral vasoconstriction caused by activation of the sympathetic nervous system. As a result, chronic stress may result in the peripheral blood diseases and ischemic cardiovascular diseases. Therefore, the measurement of the stress using PPG may be an important means to predict the state of health of an individual.

2. Body

2.1. Research Plan

We planned a method of measuring the stress level by comparing the before and after results of the experiment. First, we assessed the moods of participants using the Profile of Mood States (POMS) survey prior to the experiment. POMS survey showed five different scales, including unworthiness, anger, anxiety, depression, and vitality. PPG was measured for 3 minutes and 30 seconds while the participants was filling out questionnaires. Right after CWT, PPG was measured by assessing the mood of participants with POMS. The experimental procedure was shown in Fig. 1.

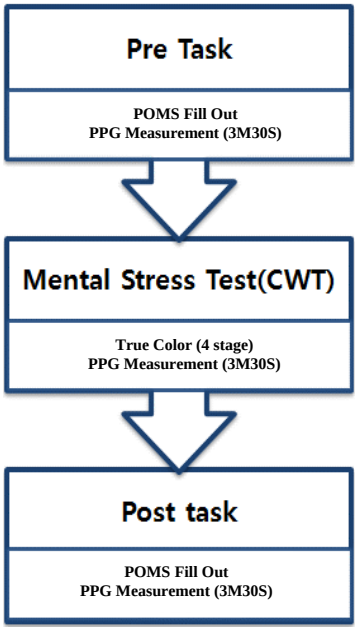


Fig. 1. Experimental Procedure.

2.2. Profile of Mood States (POMS) Survey

We evaluated the subjective mood of the test subject using the Profile of Mood States (POMS) questionnaire to assess the mood of the test subjects. The survey consisted of a total of 45 questions and each question represents the five mood states, such as unworthiness, anger, anxiety, depression, vitality (vigor). The degree of feeling was divided into five levels according to each question.

One of the difficulties in testing the correct correlation between the subjective POMS survey data and objective PPG survey data was the difference between the measured timing. The POMS questionnaire was filled in before and after receiving stress, but the PPG data were measured during the stress test. We could not measure the two types of data at the same time, but it should be measured at the same time in order to overcome these problems.

2.3. Stress Test

Stroop Color-Word Test (CWT) is known to apply stress using the Stroop effect. Stroop effect is a phenomenon that shows a difference in the speed of reading the letters when reading the letters only, and then when the font color doesn't match with the letter. Using this phenomenon, stress was given by an application called 'True color' created by Aurélien Hubert. True color is composed of 4 step game. The first step is to select the word that matches the color and the word expressing that color. The time limit for a question is 5 seconds and the correct answer should be entered within the time. The more correct answers that are entered, the time limit shortens. The score is calculated by the number of correct answers, and the game ends immediately when the answer is wrong. The second step is to test how many correct answers were entered to the given questions within the time limit. The time limit is 30 seconds, and the game method is the same as the first step. However, the game doesn't end even if the answer is wrong, but 1 score will be deducted from the score with every wrong answer. In the game of the third step, the color and the word that describes the given color is different, and the participant needs to find the color that matches with a word from the given examples. In this game, eight kinds of colors are given and the correct answer should be entered within five seconds. Like the first step, the more correct answers that are entered, the time limit decreases, and the game ends immediately with the wrong answer. Finally, four examples of the color and the word describing the given color will be shown in the fourth step. Here, the participant needs to find the one that matches. The time limit is 3 seconds, and the game ends immediately when the answer is wrong.

3. Experiment

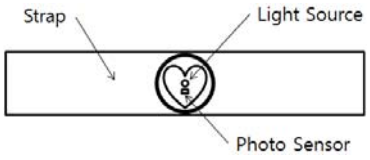
3.1. Test Subject

We recruited test subjects prior to experiment. Target subjects were men and women who were in good health (average age 23 years old ± 2), with no cardiovascular disease, no color blindness, never took medication, not pregnant, and had no experience of CWT. In addition, the experiment was conducted when the test subjects had plenty of rest, consumed no alcohol within the 12 hours' time frame of the experiment, and were not in a state of extreme physical fatigue.

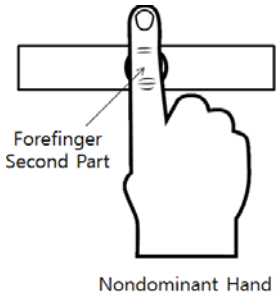
3.2. The Data Measurement

We use the PPG sensor used in Arduino to measure PPG. A schematic diagram of the equipment is shown in Fig. 2(a). The PPG sensor has a photo sensor that receives the light source and the light. The second

segment of the non-dominant hand's index finger is laced over the sensor and wrapped with a strap. A schematic diagram of this wearing method is shown in Fig. 2(b). Data collection was conducted by using the serial communication between Arduino UNO and Desktop Computer, and Matlab was used in this procedure.



(a)



(b)

Fig. 2. (a) PPG Sensor equipment schematic diagram, (b) PPG Sensor wearing schematic diagram.

3.3. Data Analysis

PPG data of the test subjects measured by each step were analyzed using the Matlab. After reducing the high frequency noise using a Hamming Window, the Fast Fourier transform (FFT) was conducted. Hamming Window is shown in Equation (1).

$$\text{Haming Window} = 0.54 - 0.46\cos\frac{2\pi n}{N} \quad \text{for } n = 0,1,2,\cdots,N-1 \tag{1}$$

The obtained frequency band is divided into a low frequency band (LF: 0.04 ~ 0.15 Hz) and high frequency band (HF: 0.15 ~ 0.4 Hz). According to several reports, LF is a low-frequency region and reflects the activity of the sympathetic nervous system, and HF is a high frequency region and reflects the activity of the respiratory system and the parasympathetic nervous system. The Heart Rate Variability (HRV) is a measurement the activity of the autonomic nervous system by using the ratio of these two values. HRV is shown in Equation (2).

$$\text{HRV} = \frac{\text{LF}}{\text{HF}} \tag{2}$$

In our data, HRV was reduced when the experimenters conducted the test at the pre-task conditions. And HRV was restored in the post-task conditions after the stress tests had been completed. Table 1 displays the average of the experimenter frequency data, and the HRV data of each test subject is shown in Fig. 3. The psychological state of the experimenter was changed to positive overall when compared before and after the stress test. The data of the negative items fell sharply. Average psychological state data of the experimenters is shown in Table 2.

In addition, we could observe the changes in heart rate (HR). The HR of all experimenters was increased during the stress test. This was seen as a result of the tension and excitement for the game. HR data for each experimenter is presented in Fig. 4.

Table 1. The average frequency data of the experiment.

	Average	
Unworthiness	16.75	14.41667
Anger	15.5	15.08333
Anxiety	22.08333	17.16667
Depression	21.5	17.08333
Vitality	30.75	29.25

Table 2. Average psychological state data of the experimenters.

	Average		
	LF	**HF**	**HRV**
Pre-task	320685.7	268035.1	1.217443
CWT	306024.1	337286.9	1.00752
Post-task	347666.2	360008.7	1.070755

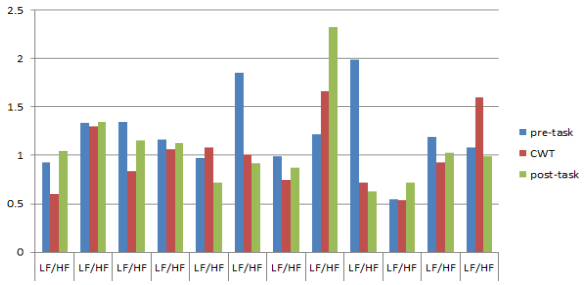


Fig. 3. LF/HF (HRV) data graph by steps of test subjects.

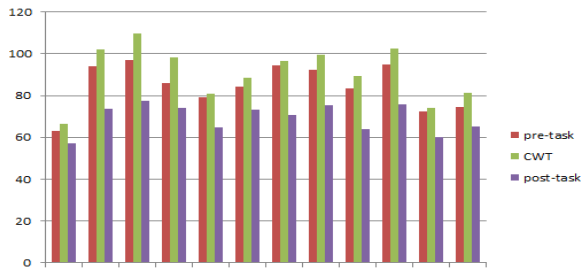


Fig. 4. Graph of heart rate data in steps of each test subjects.

In general, positive emotions (e.g. appreciation) increases both the high-frequency component (HF) and the low frequency components (LF), so there is no changes in LF / HF ratio. On the other hand, negative

emotions (eg. anger, frustration, and sadness) are known to cause no change in the high-frequency component (HF), but clearly increases the low-frequency component (LF). Our test results shows that average HRV of the experimenters decreased while conducting the stress test. It also showed a positive change in the mood state data with the POMS survey. Therefore, we could find the correlation between the autonomic nervous system activity index and the mental stress.

4. Conclusion and Future Research Directions

HRV, physiological indicators, using the PPG data was found to be changed by mental stress. Our results indicate that PPG measurement may be one of the easiest ways to assess the mental stress quantitatively. In a subsequent experiment, it is necessary to find out the relationship between the physiological indicators and various types of psychological stress.

Acknowledgements

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