Evaluation Of Mental Stress And Heart RateVariability Derived From Wrist-Based Photoplethysmography

Chongyan Chen, Chunhung Li, Chih-Wei Tsai, Xinghua Deng

Introduction

• Heart Rate Variability (HRV) has been widely recognized as an important indicator of physical fitness and mental stresses.
• Electrocardiography (ECG) is the most common means to detect HRV. However, the nature of active detection limits its convenience and usage time.
• Wrist-based Photoplethysmography (PPG) provides the possibility of convenient 24/7 HRV monitoring. However, its accuracy has not been systematically analyzed.

Research Questions

• Which PPG performs better in detecting stress state, Infrared (IR) or Green Light?
• How short the temporal window could be?
• Which HRV features are valid for stress detection?
• Could HRV features extracted from PPG recognize the mental stress as accurate as ECG?

Methods

Data Collection

Subjects: 6 subjects, ages 21-40 years old.

Devices:

Glutrac
PPG from wrist
• Green/ Infrared Light

Polar H10
ECG from chest
• R-R Interval

Tasks:

Relax 10 mins → Induce Stress 10 mins (Perform Mental Arithmetic (subtract the number 13 from the number 1,022 serially [1]) in front of an audience.) → Relax 10 mins

ECG R-R intervals filter and PPG pre-processing

The relationship between R-R/P-P Intervals and ECG/PPG waveform are demonstrated in Fig. 1.

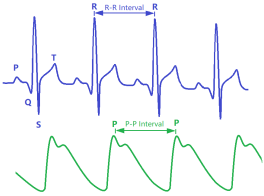

Fig. 1. ECG waveform and PPG waveform.

We applied a bandpass filter to remove noise and dropped intervals outside the range of 500-1200 ms for R-R/ P-P intervals, shown in Fig. 2.

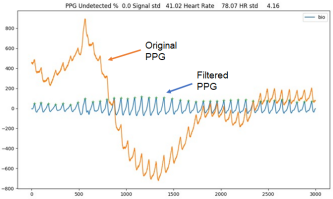

Fig. 2. Raw and filtered PPG waveform.

Examples of the R-R Intervals for one subject during the experiment is shown in Fig. 3.

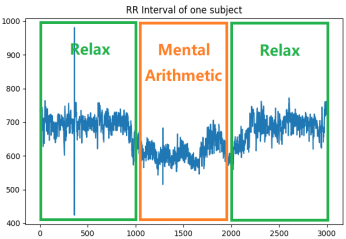

Fig. 3. R-R Interval (ms) of one subject.

HRV analysis

We then used 1 min, 3 mins and 5 mins moving window with half overlapping to calculate 16 HRV parameters [2] derived from R-R Intervals and P-P Intervals.

Stress detection using HRV

a. To select better PPG light and appropriate window size, we built an individual stress prediction model based on Random Forest (RF). The evaluation metrics are 10-fold cross validation mean accuracy.

b. We chose ANOVA as a hypothesis test model to see which HRV feature has a significant difference between stress state and non-stress state. $P < 0.05$ is considered statistically significant.

c. To build a generalization model to predict stress state, we used a standard scaler to scale the data. Then we used Leave-One-Participant-Out (LOPO) cross-validation to train and test data based on RF. The evaluation metric is F1 score.

Results

a. Both ECG and PPG reach a high accuracy using 3 or 5 minutes window size. Overall, the green light is slightly better than IR.

TABLE I.
DETECT STRESS STATE- INDIVIDUAL MODEL

Time	ECG	IR	Green Light
1min	90.07%	83.92%	84.52%
3mins	97.58%	96.29%	98.00%
5mins	97.94%	98.23%	98.48%

b. Table III shows ten HRV parameters that have significant differences between stress and non-stress states.

TABLE II.
HRV HYPOTHESIS TEST

HRV features	ECG (3mins)	ECG (5mins)	Green Light (3mins)	Green Light (5mins)
SD1	0.075	0.085	**0.000102**	**3.69E-05**
SD2	0.374	**0.037**	**0.0031**	**7.17E-06**
RMSSD	0.075	0.086	**0.000102**	**3.70E-05**
SDNN	0.204	**0.044**	**0.000715**	**3.55E-06**
MHR	**1.83E-07**	**9.95E-09**	**0.027**	**0.0086**
MRRI	**8.83E-07**	**2.45E-08**	0.176	0.1
Total Power	**0.041**	**0.015**	**0.0028**	**3.94E-06**
VLF	0.932	**0.035**	0.148	**0.000275**
LF	**0.034**	**0.017**	**0.008**	**1.11E-06**
HF	**0.006**	0.265	**0.0017**	**7.25E-07**

c. Generalization model achieves an overall F1 score of 80% in PPG dataset while ECG reaches 79.7%.

TABLE III.
DETECT STRESS STATE- GENERALIZATION MODEL

Participants	ECG (5mins) F1 score	IR (3mins) F1 score	Green Light (5mins) F1 score
P1	0.86	0.96	1
P2	0.94	0.87	0.67
P3	0.94	0.96	0.92
P4	0.57	0.69	0.71
P5	0.86	0.5	0.8
P6	0.62	0.83	0.75
Overall	0.797	0.802	0.807

In Table I, II and III, we observed that green light PPG performs even slightly better than ECG. The reasons might be that raw RR Intervals from Polar have quality issues including the loose contact of the electrodes with the subject's skin, some Bluetooth issues in the polar setup, some movement of the subject during the experiment.

Conclusions

• For PPG signals, we suggest using green light rather than infrared (IR).
• The temporal window could be as short as three minutes, which means that this detecting stress method could be applied to daily life stress state detection.
• Ten HRV parameters computed shown in Table III are valid for stress detection.
• Consumer-grade wrist-based PPG can detect HRV and recognize mental stress as accurate as ECG.

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Important References:
[1]. Kirschbaum, Pirke, and Hellhammer, "The trier social stress test–a tool for investigating psychobiological stress responses in a laboratory setting", 1993.
[2]. Kim et al. "Stress and heart rate variability: A meta-analysis and review of the literature", 2018.
[3]. Selvaraj et al. "Assessment of heart rate variability derived from finger-tip photoplethysmography as compared to electrocardiography", 2008.
[4]. Russoniello et al. "A measurement of electrocardiography and photoplethesmography in obese children", 2010.