

# Comparison of Heart Rate Variability from PPG with That from ECG

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**Abstract**— Because it is more convenient to measure photoplethysmography (PPG) than ECG, PPG is supposed as a surrogate of ECG for heart rate variability (HRV) analysis. In this study, we measured the spectrum of pulse rate variability (PRV) from PPG and its square coherence spectrum with HRV from ECG before and after exercise. The results showed that the spectrum of PRV corresponds almost well with HRV, especially for the healthy subjects at rest. However, stimuli conditions such as exercise will decrease the correlation, especially for the high frequency (HF) component. It indicates that whether PRV can be used as an alternative to HRV depends on the applications and conditions.

**Keywords**— Pulse rate variability, heart rate variability, spectrum, squared coherence spectrum.

## I. INTRODUCTION

The oscillations of cardiovascular parameters are widely used for evaluating the regulation between autonomic nervous system (ANS) and cardiovascular system, and are expected to provide information for the prediction and prevention of cardiovascular disease [1]. An example widely used is the heart rate variability (HRV). It is usually measured by spectral analysis of the R-R interval from ECG signal. The low frequency (LF) component of HRV reflect the sympathetic activities of ANS while the high frequency (HF) component reflect the parasympathetic (vagal) activities, which are corresponding to the respiratory rhythm [1]. A heartbeat will generate a corresponding PPG pulse at peripheral position. Compared to ECG monitoring which needs to attach several electrodes on the body, PPG monitoring at peripheral position is much more convenient. The sensors can be embedded in the phone camera, ring, glass, chair, or bed sheet for unobtrusive measurement. Therefore, PPG was proposed as a surrogate of ECG for the analysis of HRV [2, 3, 4]. In this study, we will measure the pulse rate variability (PRV) by spectral analysis of the peak-peak interval from PPG signal and its coherence with HRV from ECG before and after exercise, to examine whether PPG can be used as an alternative signal for ECG for the analysis of HRV.

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## II. METHODOLOGY

### A. Experiment Protocol

Eight young healthy subjects were recruited in the experiment. At the beginning of the test, ECG and PPG were collected simultaneously for 5 min while the subjects were sitting quietly on a chair. Then, the subjects were directed to run on a treadmill at the speed of 9 km/h for 3 min. After exercise, the ECG and PPG were collected simultaneously for 5 min again. ECG and PPG were collected from the subject's fingers using a system developed by the Joint Research Centre for Biomedical Engineering, Department of Electronic Engineering, Chinese University of Hong Kong. The sampling rate of the signals is 1kHz.

### B. Data Analysis

The R-R interval (RRI) was calculated as the time interval of two successive R peaks of the ECG signal. The peak-to-peak interval (PPI) was calculated as the time interval of two successive peak of the first derivative of PPG signal, as shown in Fig.1. PRV and HRV were measured as the power spectrum distribution (PSD) of the PPI-t and RRI-t series, respectively.

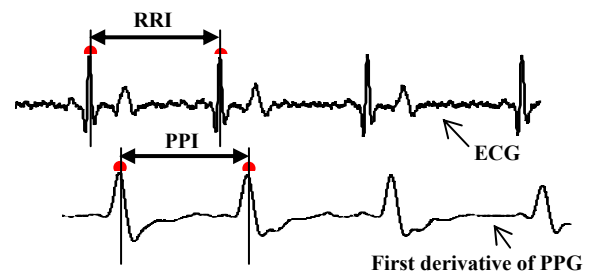


Fig. 1: Definition of RRI and PPI.

a) *Peak detection*: The R peaks from ECG and the peaks from PPG were detected using the combination of Wavelet and Amplitude methods which were with quite high noise tolerance. The detection results were also double checked by manual. The segments of original data with strong noise resulting in detection failure of peaks were removed.

b) *PSD of PRV*: PPI series were first interpolated using the cubic spline to arrive at a unified sampling rate of 2.5 Hz. DC was removed by subtracting the mean value of the series. A high-pass filter with cutoff frequency of 0.03Hz was then adopted to eliminate the very slow trends. Finally, the spectrum of PRV was estimated by means of the fast Fourier transform (FFT) with a widow length of 256. The time lengths of the PPI series analyzed were 1 min, 3 min and 5min respectively to reveal the effect of recording length on the PSD of PRV.

c) *Comparison of PRV and HRV*: PSD of PRV and HRV were calculated before and after exercise. The time length of the PPI and RRI series analyzed was 5 min. Squared coherence spectrum between PRV and HRV was also calculated before and after exercise. The squared coherence spectrum  $C_{xy}(f)$  is a measure for evaluating how well a signal corresponds to another signal at each frequency. The  $C_{xy}(f)$  has values between 0 and 1, and the higher value indicates the higher correlation. The  $C_{xy}(f)$  of two series  $x$  and  $y$  is defined as the equation followed [5]:

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)} \quad (1)$$

where,  $P_{xx}(f)$  and  $P_{yy}(f)$  are the PSD of  $x$  and  $y$ , and  $P_{xy}(f) = X^*(f)Y(f)$  is the cross PSD of  $x$  and  $y$  (\*indicates the complex conjugate).

The coherence strengths between PRV and HRV at the LF and HF components were evaluated by calculating the mean squared coherence spectra at frequencies of the corresponding band. In this study, the LF band was defined as the frequencies between 0.04 and 0.15 Hz, while the HF band was between 0.15 and 0.4Hz, as described in [1]. The mean squared coherence spectra between PRV and HRV at LF and HF bands were respectively calculated for each of the subject before and after exercise. After that, mean $\pm$ SD of the mean squared coherence spectra were calculated for the 8 subjects.

### III. RESULTS

Fig.2 shows a typical example of PSD of the PRV when time lengths of the PPI series analyzed increased from 1 min to 5min. It can be seen that time length of 1min is too short to reach a stable PSD with other time lengths (3min and 5min), while the PSD with time length of 3 min and 5min are almost the same. It indicates that PPI series with time lengths between 3 min and 5 min are suitable for analyzing the PSD of PRV.

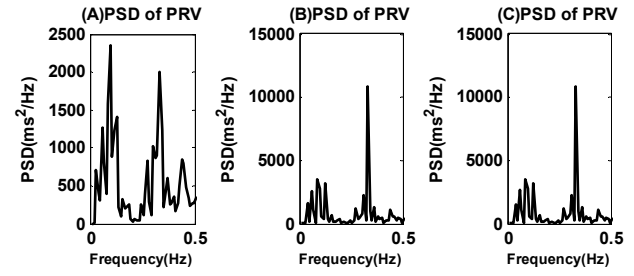


Fig. 2: The effect of recording length on the PSD of the PRV. The recording lengths of PPI-t series analyzed in (A), (B), (C) are 1min, 3min, and 5 min respectively. PRV indicates pulse rate variability; PSD, power spectrum distribution.

Fig.3 shows a typical example (the same subject as in Fig.2) of PSD of the PRV and HRV before and after exercise (the upper panel). The squared coherence spectrum between the same PRV and HRV is shown at the bottom panel. It can be seen that PRV corresponds well with HRV before exercise. However, the coherence strength turns a little lower at HF (0.15-0.4Hz) after exercise, while the LF (0.04-0.15Hz) component remains in high coherence.

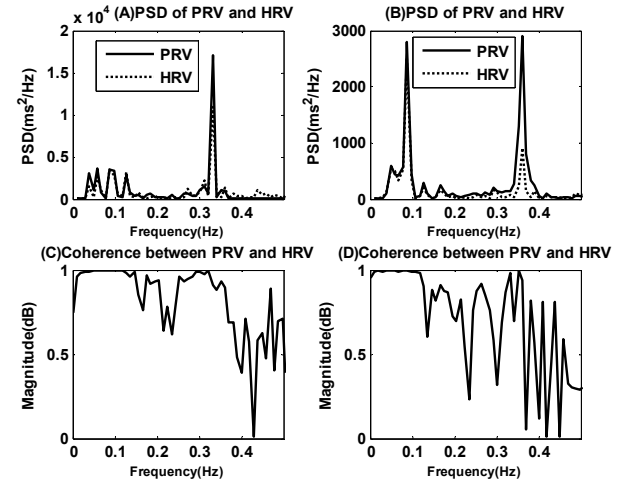


Fig. 3: The PSD of the PRV and HRV and the squared coherence spectrum between PRV and HRV at each frequency. (A) (C): before exercise; (B) (D): after exercise. PRV indicates pulse rate variability; HRV, heart rate variability; PSD, power spectrum distribution.

Mean squared coherence spectra between PRV and HRV at LF component before and after exercise in 8 subjects are  $0.9825 \pm 0.0329$ ,  $0.9805 \pm 0.021$ , respectively. The values are  $0.9251 \pm 0.0596$ ,  $0.8538 \pm 0.1464$  for HF component. As shown in Fig.4, it indicates that PRV and HRV correspond well in LF than in HF, the correlation turns lower in HF after exercise.

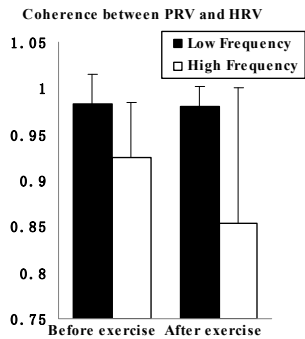


Fig. 4: Mean squared coherence spectra between PRV and HRV at LF and HF before and after exercise. (mean $\pm$ SD was calculated for the 8 subjects).

#### IV. DISCUSSION AND CONCLUSION

The results indicate that the PSD of PRV corresponds almost well with HRV, especially for the healthy subjects at rest. However, stimuli condition such as exercise will decrease the correlation, especially for the HF component. The reason can be that the HF component of PRV will be more susceptible to peripheral conditions such as arterial blood condition and respiratory movements than HRV. The correlation of the PRV and HRV should be further verified in broader conditions and in different kinds of patients that with pathological ECG wave (e.g., patients with extrasystoles or premature contractions). Hence, whether PPG can be used as an alternative signal for ECG for the spectral analysis of HRV depends on the applications and conditions according to this study.

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#### CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

#### REFERENCES

1. Malik M, et al. (1996) Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology. *Eur Heart J* 17: 354-381
2. Hayano J, Barros A K, Kamiya A, Ohte N, Yasuma F (2005) Assessment of pulse rate variability by the method of pulse frequency demodulation. *Biomed Eng Online* 4:62
3. Kageyama T, Kabuto M, Kaneko T, Nishikido N (1997) Accuracy of Pulse Rate Variability Parameters Obtained from Finger Plethysmogram: A Comparison with Heart Rate Variability Parameters Obtained from ECG. *J Occup Health* 39: 154-155
4. Schäfer A, Vagedes J. (2012) How accurate is pulse rate variability as an estimate of heart rate variability?: A review on studies comparing photoplethysmographic technology with an electrocardiogram. *International Journal of Cardiology*. 166: 15-29
5. Ma H T, Zhang Y T (2006) Spectral analysis of pulse transit time variability and its coherence with other cardiovascular variabilities, *Proc. 26th IEEE EMBS Annu. International Coni, New York, USA, 2006*, pp. 6442-6445

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