A Research on the Feasibility of Cardiac Output Estimation Using Photoplethysmogram and Ballistocardiogram

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***Abstract*— This study investigated the feasibility of photoplethysmogram (PPG) and ballistocardiogram (BCG) for daily life cardiac output (CO) monitoring. The two treatments used to create change in CO were intense exercise and Valsalva maneuver, while PPG and BCG as well as generally used non-invasive standards were used. The results showed that the mean amplitude in the PPG signal had a positive relationship with the CO in both tasks. The mean amplitude of the BCG signal also had a positive relationship with the CO in the exercise, but during the Valsalva breathing, the amplitude of the BCG signal inversely increased. Overall, it was concluded that both PPG and BCG signals could be appropriate indicators for daily life CO monitoring.**

I. Background

Cardiac output (CO) is the amount of blood pumped out of the heart per minute. It is directly related to the power of the heart and how well is the circulatory system functioning. [1] Despite of its importance and usefulness, there are currently no methods of measuring CO that is inexpensive, continuous, and self-administrable. In this research, two technologies, photoplethysmography (PPG) and ballistocardiography (BCG), were assessed on how adequate they were in measuring CO. PPG uses light reflections of the blood streams in vessels to determine the variation of the blood volume, while BCG operates by using the vibrations of the human body due to motions of the heart. [2] The treatments used in this experiment were discovered to have an impact on the heart rate and the stroke volume. Using these treatments, the responsiveness and the effectiveness of BCG and PPG in measuring CO were examined.

II. Method

A healthy male subject went through the Finometer / Valsalva breathing portion and the Doppler ultrasound method (DUM) / exercise portion. In the Finometer / Valsalva breathing portion, the subject wore the Finometer, the PPG, and the BCG. Data measured from those instruments were collected before, during and after Valsalva treatment. In the DUM / exercise portion, the subject also wore PPG, BCG, and DUM equipment. The values were measured before and after 10 minutes of intense stair-running exercise.

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III. Results / Conclusions

The following dependent variables were calculated using MATLAB. Visualization of both waves are also given.

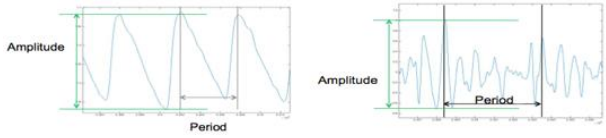

Figure 1. Example of PPG and BCG waves, respectively

These results showed that mean amplitude of PPG followed the changes in the standard measurements well, in terms of increase and decrease. The mean amplitude of the BCG signal also had a positive relationship with the CO in the exercise. But during the Valsalva breathing, in which the CO dropped significantly, the amplitude of the BCG signal inversely increased. This result is likely derived from the increase of intrathoracic pressure, and the consequent decrease of venous return and heart contractibility. To adjust this discrepancy in the variation pattern of the amplitude of BCG signals between Valsalva breathing and exercise, the recovery time could be considered. On the whole, both PPG and BCG signals have the potential to be appropriate indicators for daily life CO monitoring. Since both of them are not feasible as of now, however, further research should be conducted in this area to control variables such as age, gender, and BMI. Between the two technologies, other variables in the body that complicate the BCG signals make PPG a more likely choice as of now.

TABLE I. Table of Mean Amplitudes for Exercise

Measurement	***Before***	***After***
DUM (CO in L/min)	5.5544	10.800
PPG	0.1533	0.2013
BCG	1.8125	2.6530

TABLE II. Table of Mean Amplitudes for Valsalva Breathing

Measurement	***Before***	***During***	***After***
Finometer (CO in L/min)	5.148	3.655	5.512
PPG	0.1935	0.1404	0.2518
BCG	2.0322	2.3775	2.0528

References

[1] Critchley, Lester, Anna Lee, and Anthony Ho. "A Critical Review of the Ability of Continuous Cardiac Output Monitors to Measure Trends in Cardiac Output." Anesthesia & Analgesia 111, no. 5 (2010): 1180-1192.

[2] Mohamed Elgendi, "On the Analysis of Fingertip Photoplethysmogram Signals."Current Cardiology Reviews 8, no. 1 (2012): 14-25.