

Evaluation of a Combined PPG/MPG Sensor in Healthy Volunteers

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Background: Conventional pulse oximetry uses light absorption to detect volumetric changes in arterial blood over time, captured in the photoplethysmogram (PPG) [1]. Complementary data, from a change in blood pressure, will allow for the exploration of the pressure-volume relationships in the cardiac cycle. We previously reported how a brass disk with a ceramic piezoelectric coating can be integrated into a regular pulse oximeter finger boot [2] to obtain a mechano-plethysmogram (MPG). The aim of this work is to refine this prototype and record pilot data in a variety of both positions and vasotonic conditions.

Methods: The optical elements of a Nellcor pulse oximeter clip sensor were mounted in a custom 3D printed shell, allowing a piezo disc to be suspended directly under the photodiode for co-located measurements of PPG and MPG. With research ethics board approval and written informed consent, ten healthy volunteers were recruited. The combined PPG/MPG clip was attached to the index finger of the dominant hand. Participants were seated in a chair. Measurements were taken under five conditions; three positional measurements (a, b and c; performed for 60 seconds each), and two conditions studying vasoconstriction (d) and vasodilation (e).

- a) Baseline: sensor slightly below the heart level on a flat surface.
- b) Minimum height: hand hanging by the side of the chair.
- c) Maximum height: sensor elevated maximally above the head.
- d) Cooling: after immersion in ice water (for 60 seconds or as long as tolerated), the hand was placed at baseline height and data was collected for 120 seconds.
- e) Warming: after rewarming using a forced air warming blanket (for 5 minutes), the hand was placed at baseline height and data was collected for 60 seconds.

Data from both PPG/MPG were collected with a Datex-Ohmeda S/5 multi-parameter patient monitor synchronously through two identical invasive pressure interfaces at 100Hz. PPG and MPG amplitudes were extracted using MATLAB; their phase delays were calculated using peak time differences; and MPG-PPG loops [3] were created for each position. Comparisons in amplitude and phase were performed using Wilcoxon signed-rank tests, without adjustments for multiple comparisons. To estimate noise, spectrograms of the MPG segments were compared to segments of the first derivative of the PPG.

Results: The data from 10 volunteers show that the MPG is similar, but not identical to, the PPG first derivative. It was possible to determine key features of the cardiac cycle in the MPG waveform including systole, diastole, and the dicrotic notch. Compared to Baseline, MPG amplitude decreased for the Minimum height position (median difference [MD]: -39.0), but not the Maximum height position; vasodilation increased the MPG amplitude (MD: 59.5), but no changes in PPG amplitude were observed (Fig. 1 left). The phase shift between the MPG and PPG was small and did not change with position or vasotonic condition. MPG/PPG loops grew in size with warming and showed additional features (peaks) in the MPG component (Fig. 1 right).

MPG was significantly noisier than PPG, as seen by higher amounts of power across the entire frequency spectrum, particularly in frequencies over 30Hz.

Conclusion: There may exist untapped physiological information about the cardiac cycle (e.g. cardiac valve opening/closing) in the MPG waveform as some peaks and troughs are cleaner and more reproducible in the MPG waveform than the first derivative of the PPG. Future work, including a sensor redesign aimed at improving the signal-to-noise ratio, will explore this opportunity further.

References: [1] Electronics. 2014; 3:282-302. [2] Anesth Analg. 2017;124(5S_Suppl):110-1. [3] J Clin Monit. 1997;13(4):223-8.

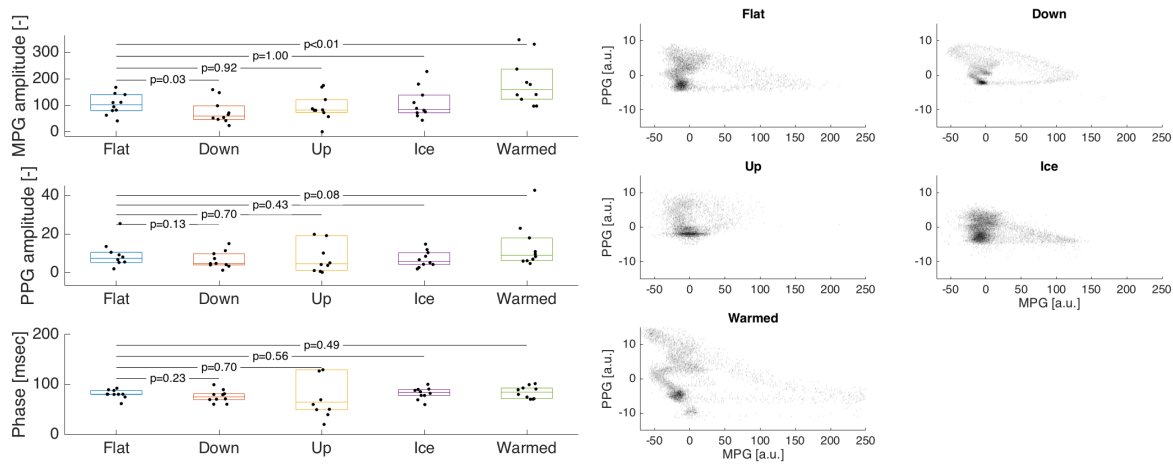


Figure 1: MPG and PPG comparison. The left subplot shows MPG amplitude (top), PPG amplitude (middle) and phase delay of MPG and PPG (bottom) in the three positions (a, Baseline/Flat; b, Minimum/Down; c, Maximum/Up) and (d) vasoconstriction (after cooling in Ice) and (e) vasodilation (after being Warmed); the right subplot shows MPG-PPG-Loops, with MPG waveform values plotted against PPG waveform values for the five conditions (data shown as a heatmap with log-transformed intensity).