Dual channel photoplethysmography studies of cardio-vascular response to the body position changes

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ABSTRACT

The dual-channel photoplethysmography studies of physiological responses during 3-stage orthostatic test were performed. Clear differences in heartbeat rate, pulse wave transit time and blood pressure variations of healthy volunteers and diabetic patients have been observed.

Keywords: Photoplethysmography, optical bio-sensing, non-invasive, blood pulsations.

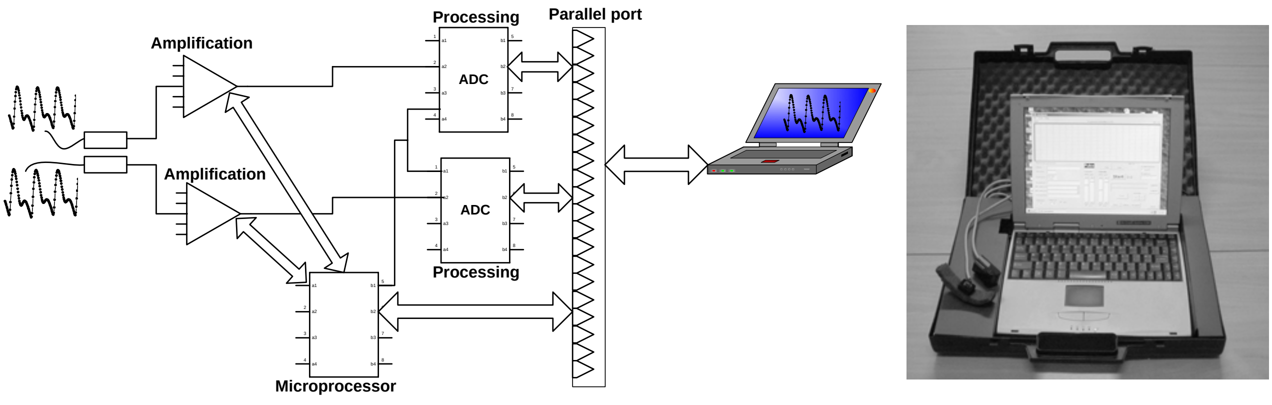
1. INTRODUCTION

The peripheral pulse analysis provides information about the cardiovascular parameters, e.g. heart rate, pulsatile pressure and properties of blood vessels including arterial elasticity, narrowing or occlusion [1- 4]. A suitable optical non-invasive technology for studies of the blood volume pulsations is photoplethysmography (PPG), especially if the multi-channel PPG approach is used. The multi-channel devices were successfully applied for cardiovascular fitness tests and for early detection of arterial occlusions in extremities [5]. The dual-channel PPG device was used in present work for clinical studies of the circulatory system responses to changes of the body orientation (horizontal-vertical-horizontal) for healthy volunteers and diabetic patients.

2. EQUIPMENT AND METHODS

2.1. Dual-channel PPG sensor device

The dual-channel device comprises two optical contact probes supposed to be applied simultaneously during the measurements, the bio-signal acquisition/conversion circuit and a laptop computer with specially developed software. All equipment is placed in a hand-held case of size 44x32x9 cm and weight 4.1 kg; it is battery-powered and can operate up to 3 hours without recharging.



a b

Fig. 1. The dual-channel PPG sensor device: functional scheme (a) and outlook (b).

Each optoelectronic contact probe emits cw-radiation into the skin tissues and detects the back-scattered radiation; the separated AC-component of the signals precisely reflects absorption changes due to the skin blood volume pulsations at the probe-covered area. Both contact probes comprise identical pair of GaAs emitting diode (diameter of the emitting area ~2 mm, radiant power ~10 mW, peak wavelength ~940 nm, the mean penetration depth ~2-3 mm) and Si photodiode (square detection area ~5x5 mm). Both diodes are closely mounted on a soft plastic pillow and fixed onto the measurement site by means of a sticky band or a finger-clip. Advantage of the band-holder design is the possibility of its flexible extension by means of spare sticky bands, so allowing to take the PPG measurements at any external location of the body, e.g. forehead, forearm, neck, belly, calf, etc.

Special software was developed for the PPG bio-signal acquisition, processing and data storage from both input channels, offering the following options:

- Filling the first window for patient data - name, age, gender, complains, doctor's comments, etc.;
- Pre-setting the measurement time schedule;
- Real-time display of both PPG signals;
- Signal clean-up (special filtering algorithm) and calculation of the mean single-period PPG (SP-PPG) signal shape;
- Calculation of specific cardio-vascular parameters for the registered signals - heartbeat rate, *anacrota* rise-time, time delay and relative amplitude of the secondary peak (*dycrotic* notch), time-shift between two corresponding PPG signals at both channels, etc.;
- Display of the selected PPG parameter set with corresponding cardio-vascular assessment results;
- Storage of the obtained data.

The data-sampling rate 200 s^{-1} was usually chosen. Screen-shot of the two-channel PPG measurement process is presented at Fig. 2. Time-shift between the signals of both channels (detected at the neck artery and fingertip) is clearly observable.

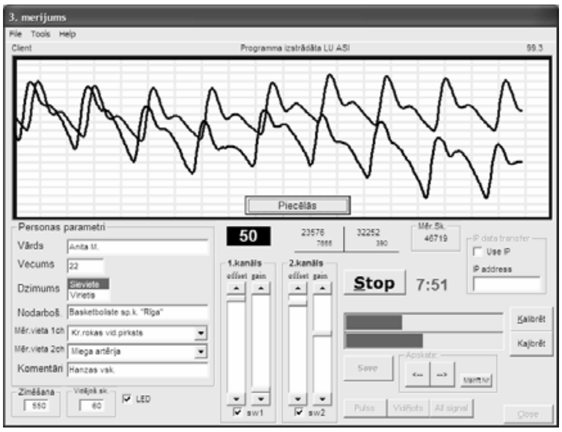


Fig. 2. The monitor screen-shot taken during the two-channel PPG measurements.

Systolic blood pressure was measured using the A&D Medical UA-767 Plus digital blood pressure monitor.

2.2. Subjects

20 healthy volunteers and 20 patients with a history of diabetes more than 1 year, aged from 26 to 75, were studied. Subject's age was chosen similar for healthy and unhealthy persons. Subjects were asked to relax 5 minutes before the measurements. All the volunteers gave their informed consent to participate in the study.

2.2. Protocol of the study

The orthostatic test was carried out at room temperature 22±2 ^{o}C using a horizontally-vertically movable hospital bed with a specially designed subject holder. Each subject was first positioned horizontally for 1 minute, then turned vertically (head-up) for 1 minute, and then returned back to horizontal position for 1 minute (Fig. 3.). The PPG recordings were taken simultaneously from the subject's right carotid artery (on the neck) and from tip of the right index finger. The blood pressure values at the upper arm were recorded periodically every 30 seconds.

Fig. 3. The three-stage orthostatic test.

Following parameters have been monitored during the clinical tests:

- heartbeat rate (HR) and its temporal variations,
- pulse wave transit time (PWTT) between the neck and fingertip,
- systolic blood pressure (BP).

2.3. Signal processing and data analysis

The analogue signals from both PPG contact probe outputs were recorded and transferred to the laptop computer using originally designed software. Initially the signals were smoothed to reduce the random noise; the PPG pulses of poor quality with obvious artefacts were discarded. The pulse wave transit time (PWTT) was recorded continuously as time delay between the corresponding PPG pulses recorded at carotid and fingertip, with subsequent calculation of the mean values and their storage on the hard disk for further analysis.

3. RESULTS

Typical variations of the measured physiological parameters (PWWT, HR and BP) during the 3-stage orthostatic test for a diabetic (a) and healthy (b) person are illustrated at Fig. 4. More pronounced responses to the body position changes were observed for the diabetic patient group. The calculated mean PWTT value ratios for different test stages (V – vertical, H1 – initial horizontal, H2 – final horizontal) are compared in Table 1. The H1/H2 ratios are close to 1 for both subject groups; however, the responses to body position change (V/H1 and V/H2) are clearly health-dependant - insignificant for healthy persons and much more pronounced for the diabetic patients.

Fig. 5. illustrates the averaged variations of PWTT and HR for the healthy and diabetic individuals in response to the body transfer from horizontal to vertical position and back: the transfer moments is marked by the dashed line.

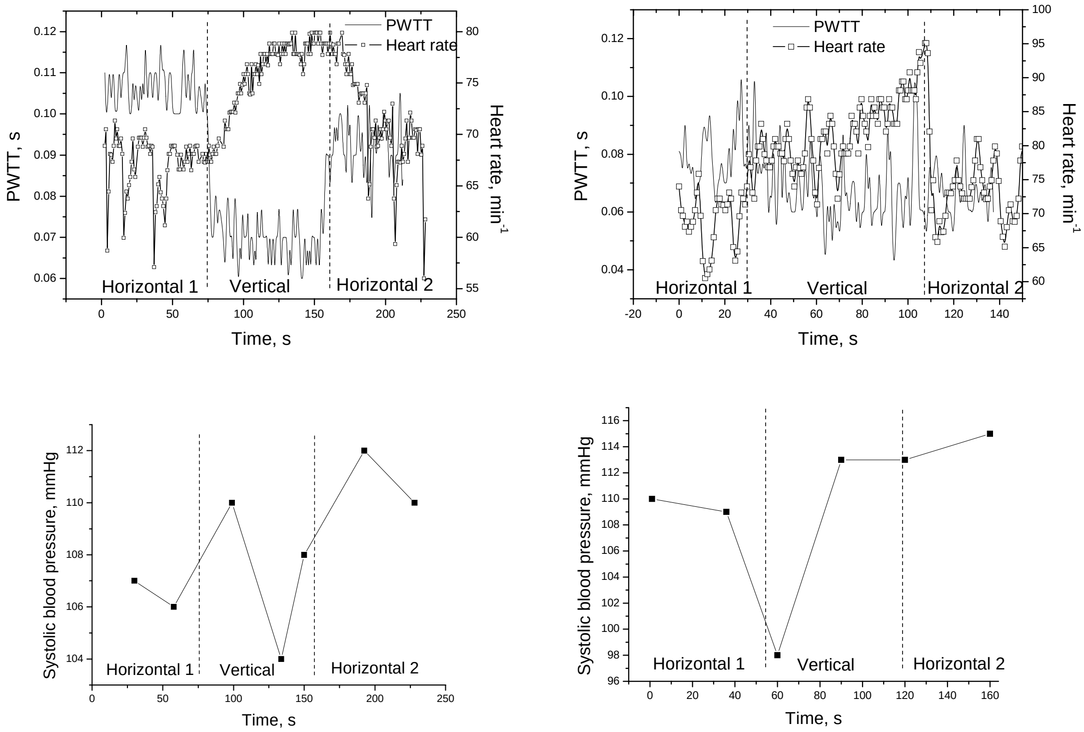


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Fig. 4. Pulse wave transit time, heart rate and blood pressure variations during the 3-stage test for a diabetic patient (a) and a healthy person (b).

Table 1. Ratios of the mean PWTT values at different stages of the test for healthy volunteers and diabetic patients*.

	Healthy	Diabetic
V/H1	96	70
V/H2	91	71
H1/H2	97	100

*) The statistic deviation $\pm$ 10%

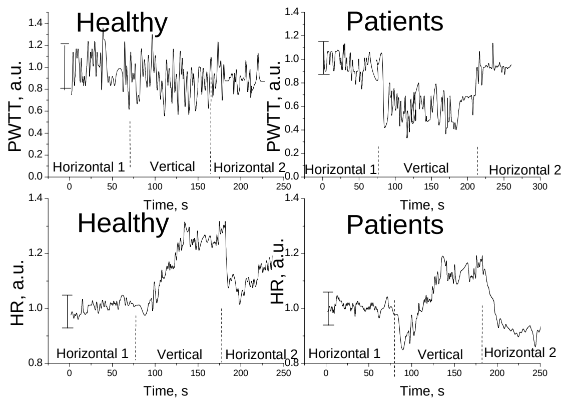

Fig. 5. The averaged variations of PWTT and HR during the body transfer from horizontal to vertical position.

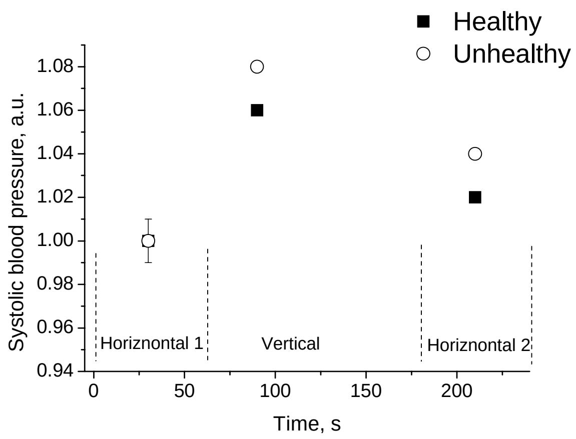

Fig. 6. The averaged relative changes of the systolic blood pressure.

The blood pressure responses to the body position changes have been very individual. Fig. 6. illustrates the changes of the systolic blood pressure averaged for all healthy and diabetic patients. The BP mean increase is somewhat higher for the diabetic patients. However, both mean values lie within the measurement uncertainty interval so there is no evidence of substantial differences from the point of systolic blood pressure between responses of healthy persons and diabetic patients.

4. CONCLUSIONS

The obtained results convincingly demonstrate suitability and potential of the developed dual-channel photoplethysmography technique for studies of cardio-vascular responses during the orthostatic tests. This approach is non-invasive, fast and patient-friendly; it seems to be promising for early diagnostics of vascular problems and also might be useful for clinical studies of drug effects. Clear differences in orthostatic responses of healthy volunteers and diabetic patients have been observed, especially regarding the pulse wave transit time (PWTT) changes – see Table 1 and Fig. 5.

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