Age-related circulatory responses to whole body cooling: observations by ballistocardiographic EMFi sensors

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AGE-RELATED CIRCULATORY RESPONSES TO WHOLE BODY COOLING: OBSERVATIONS BY BALLISTOCARDIOGRAPHIC EMFi SENSORS

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Abstract

The purpose was to study age related changes in circulatory system via Ballistocardiography (BCG) by utilizing Electromechanical Film (EMFi) sensors by gradually changing the ambient temperature from a thermoneutral area to cold direction. ECG and BCG were recorded from a young person (23 years) and from an older person (78 years), both males. During the tests, brachium blood pressure (BP) and pulse signals were recorded from neck and ankle (with EMFi sensor strips). Thermal camera images were taken in order to find out temperature changes in whole body and limbs. Temporal durations and amplitudes of seat BCG:s components (systolic and diastolic) as well as from pulse signals from neck and ankle were calculated. Aortic pulse wave velocity (PWV) was obtained by utilizing the time between ECG's R wave and maximum value of the ankle pulse signal.

In both persons, the ankle pulse amplitude decreased when propagating to cold direction and increased in young person when returning to warmer ambient temperature. With young and old BCG:s systolic and diastolic temporal complexes remained stable, but systolic amplitudes increased in the older person (A_{HI} 1.02 – 2.87, A_{IJ} 0.7 – 2.66) as well as diastolic amplitudes (old; A_{KL} 0.47 – 2.37). In the older person, PWV increased when moving to colder side. BP increased with a young person (from 95/64 to 132/75 mmHg), and with older person (from 125/68 to 176/101 mmHg) having a prominent rise in diastolic values during the cooling. The neck pulse wave amplitude A_{OP} rise was modest with the younger person and had variation with the older person. Older person had also more intensive shivering compared to younger one. With the older person, the limbs stayed cold in thermal images when returning from cold to thermoneutral area. The present preliminary observations indicated clear age-related differences in the circulatory response to a mild whole-body thermal challenge.

Keywords: EMFi, BCG, thermoneutral area, thermal balance

Introduction

Ballistocardiography (BCG) is a non-invasive method for cardiac and respiratory evaluation and it reflects closely the strength of myocardial contraction revealing the condition of the heart [1, 2]. When the heart pumps blood from atrium via ventricles to the pulmonary arteries and ascending aorta, through aortic arch to the peripheral circulation, recoil of opposite direction is applied to the body and its force and direction is changing according to the cardiac cycle. The BCG waveforms have been named as follows; Pre-ejection (FGH), ejection (IJK) and diastolic part of the heart cycle (LMN) [1]. The peak of the H coincides with the end of the tension phase and the onset of the rapid expulsion of the blood from the heart into aorta [3]. The I wave reflects the rapid acceleration of blood in the ascending aorta and pulmonary arteries around the aortic arch and into the carotid arteries. The J wave describes acceleration of blood in the descending and abdominal aorta and deceleration of blood in the ascending aorta. I-J amplitude reflects the force of contraction of the left ventricle [4] and I-J velocity reflects contractility [1]. The HI amplitude is formed mainly by the acceleration of flow in the ascending aorta and the IJ amplitude from the accelerating and after aortic arch from decelerating of blood flow in the descending part of the aorta [4].

The carotid pulse (CP) is a pressure signal indicating variations in arterial BP and volume with each heart beat. As the recording place is located very near the heart, the CP signal resembles the morphology of the pressure signal at the root of aorta [4]. The CP rises abruptly with the ejection of blood from left ventricle to ascending aorta reaching a peak called percussion wave (P). The following secondary wave is called as a tidal wave (T), caused by a reflected pulse returning from the upper body. Dicrotic notch (D) is caused by a closure of aortic valve and this can be followed by dicrotic wave (DW), which is due to reflected pulse from the lower body [5]. The direct and reflected pulses overlap, which is seen as traditional CP waveform (Fig. 1).

The arteriovenous anastomoses (AVAs) in hands, feet, toes and fingers take part the heat exchange with the environment. They are thick-walled vessels between arterioles and venules sited to the deeper layers of the skin being embedded in the subcutaneous fat [6]. In this paper a Mobile Physiological Signal Measurement Station has been used in recording BCG, carotid and ankle pulse signals with EMFi sensors [7]. The main goal of this study is to analyse differences of the seat BCG, CP and ankle pulse signals by studying temporal, amplitude, PWV and spectral differences between measured persons during cold and heat tests.

Methods

The EMFi [8] sensor is a thin biaxially oriented plastic film which is permanently polarized. Changes in the pressure acting on the film generate a charge on its electrically conductive surfaces and this charge can be measured as a current or a voltage signal. It can convert mechanical energy to electrical and vice versa. Thus the EMFi acts as a sensitive movement sensor suitable for BCG recordings. Signals from EMFi sensors were first amplified and filtered in the measurement device [7] and then directed into a notebook computer having a data acquisition card (Daqcard 6036E) and the recordings were made into ASCII format. In the recording device an active Butterworth 8. degree low pass filter was used, where the cut-off frequency was 250 Hz. In chair recordings the EMFi sensor (42 cm x 36 cm) was beneath the measured person. One EMFi sensor strip (15 cm x 2 cm) was attached on the left side of the neck near carotid artery and to the right ankle (dorsalis pedis pulse).

The test included temperature changes from thermoneutral area to colder side. Naked, resting human has a thermoneutral zone (comfort zone) in temperatures 27 – 32 C°. In this area the regulation of skin circulation is sufficient to maintain the heat loss stable during the ambient temperature change. The human core temperature stays in 37 C°. The skin insulation properties get better, when the small skin arteries constrict (vasoconstriction) and blood circulation decreases. During body cooling the motoric nerve fibers in muscles activate causing rhythmic involuntary constriction (myokymia) having a frequency of 10 – 20 constrictions in second. During muscle constriction muscles constrict to the same time; visible movement is not seen and muscle work is not done, but the whole increase in muscle cell metabolism converts almost completely to the heat. It is so efficient, that the heat production of the body can be multiplied in few seconds. The body temperature decrease below 25 C° is mortal and may lead to ventricular fibrillation [9]. Myocardial infarction and cardiovascular (CV) related mortality increase in low outdoor temperature [10].

Measurements

This study was made at the Thermal Environment Laboratory, Lund University. The initial air temperature was 27.5 C° and the airflow in the chamber was 0.45 m/s. After 20 min of conditioning, the temperature was progressively decreased to 16 C° at an average rate of about 0.2 C°/min and then increased quickly back to 32 C° to restore the comfort of the subjects. The recordings were made from the seat BCG, carotid and ankle pulse signals from two persons, young (20 recordings) and old (18 recordings), in a sitting position measured with EMFi sensors. All the measurements lasted 5 min and the used sampling frequency was 500 Hz. Just before the measurements the blood pressure and the pulse were measured with Omron M5-I BP monitor device.

The R wave of ECG was used as a reference in detecting the slopes from BCG and CP signals. The right ankle pulse signal was used to obtain PWV, as it reflects aortic BP and is a measure of aortic elasticity. Signals were first band pass filtered (0.5 – 30 Hz FIR, 700 taps, time delay corrected), down sampled into 100 Hz and the analysis was done with 0.5s window length. The index of the R point was detected first by differentiating (2 points), squaring and integrating (5 points) and by taking the maximum from the ECG signal. The I slope from the BCG was detected by local minimum method and then the J slope was detected by local maximum using the index of the I point as a starting point. Other slopes were detected at the same way. Amplitude spectrum was calculated from raw signal, cumulated (by adding current spectrum value to amplitude scaled value) and normalised. In order to study contraction of the left ventricle, amplitudes related to systolic phase H-I (A_{HI}), I-J (A_{IJ}), J-K (A_{JK}), K-L (A_{KL}) and to diastolic phase L-M (A_{LM}) and M-N (A_{MN}) from the BCG signal were extracted. Also the mean duration of the time intervals of the waveforms with reference to the R wave of the ECG from seat BCG and ankle pulse signals were extracted. T_{RH} is the measure of the isometric tension phase of the ventricles. T_{RK} is the duration of the mechanical systole of the heart [3].

Results

When obtained recordings were compared between young and older person, notable amplitude elevations were detected especially with older person, both in systolic and diastolic seat BCG amplitudes (Fig. 7). BP elevated with both persons when moving to cold side being higher with an older person and smaller with a younger person. Systolic BP values seemed to rise more than diastolic BP values. HR values had prominent increase with an older person and modest increase with a younger person when moving to cold side. Aortic PWV values (Fig. 4 legend) reflected closely values obtained with BP meter during cold test. Ankle pulse amplitude decreased with both persons with cold test (Figs. 4, 8). With the younger the neck amplitude and temporal values stayed pretty stable during cold test and with the older person temporal values stayed relatively stable, but neck amplitudes elevated likely due to increase in BP (Figs. 3, 6, 8).

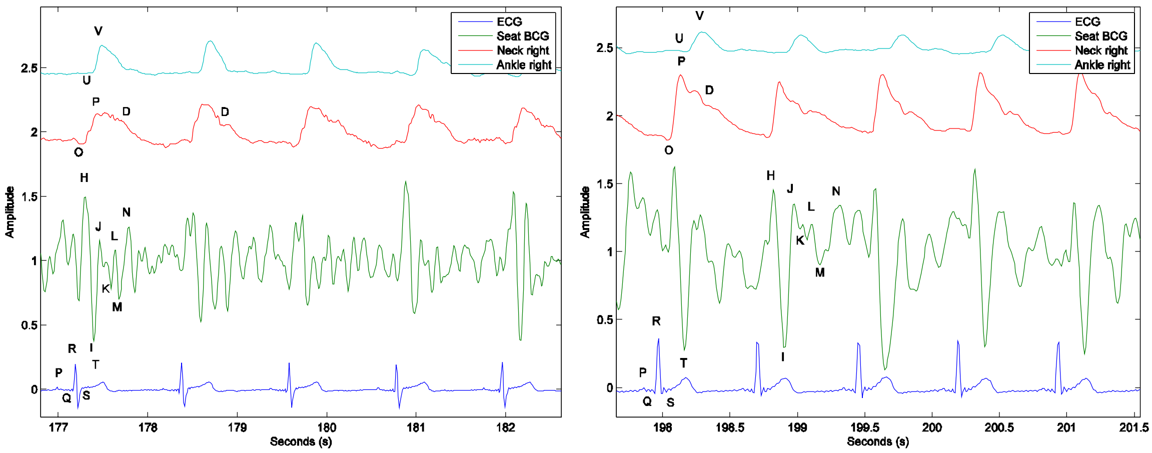

Figure 1. Signals recorded in sitting position from the older (left) and the younger (right) persons during cold test. The younger had BP 125/68, pulse 50 and the older had BP 106/66, pulse 75. Signals from the bottom to top: ECG, signal from the EMFi sensor on a chair, from the carotid artery and from the right ankle recorded with EMFi sensor strips.

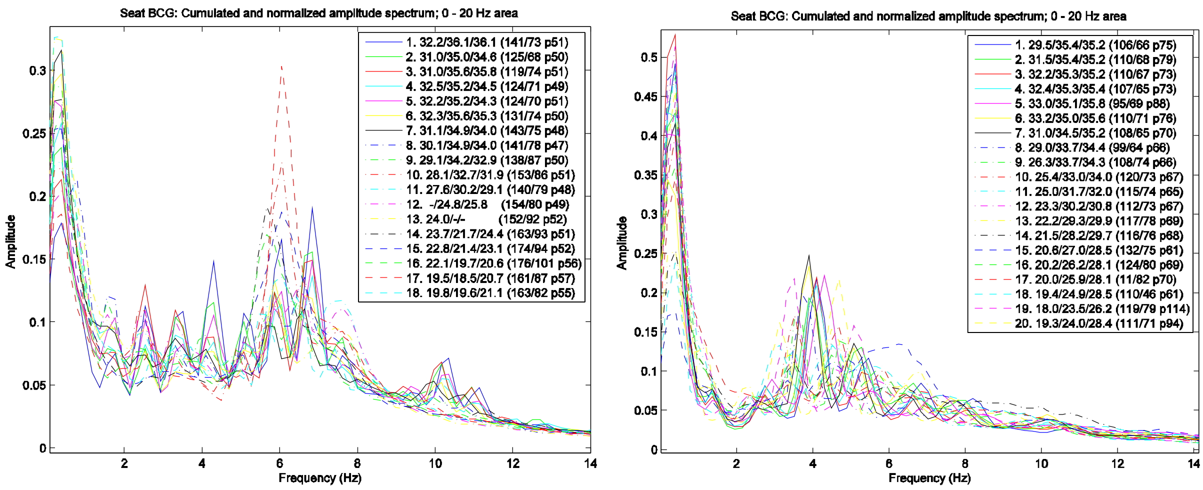

Figure 2. Spectrum from seat BCG from the older (left) and younger person (right) during the cold test. Decreased temperature elevated spectral spike amplitudes especially in lower frequencies (0.4 Hz being equivalent to 2.5s; systolic complexes). Large amplitude spike in 6 Hz (0.17s) appeared, when the systolic BP showed higher value and skin temperature lower value. Picture on the right: Decreased temperature seemed to have modest effect to spectral spike amplitudes. The transition of spectral spikes to lower frequencies (after 3 Hz) is probably due to changes in HR. When compared to older person, the spectrum is more regular and the amplitudes of the spectral spikes were lower. Temperature values were measured from the left foot; left hand and nose and are depicted after ordinal number.

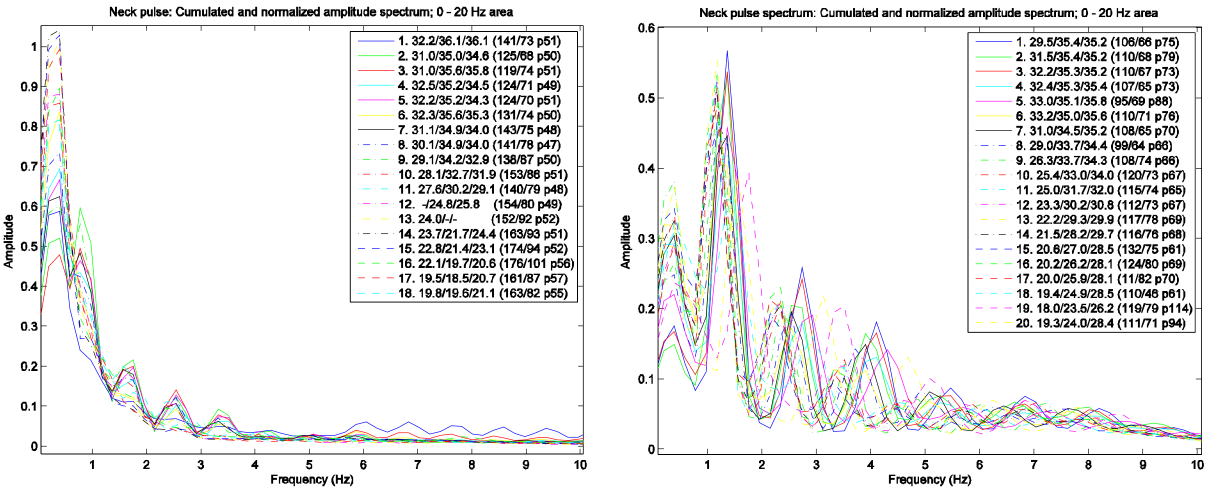

Figure 3. Pulse spectrum from the neck pulse from the older (left) and younger person (right) during the cold test. Decreased temperature with the older seemed to increase spectral spike amplitudes especially in 0.3 Hz having higher BP and lower skin temperature values. When compared to starting trace (1) the spectral spike amplitudes almost doubled in last recordings having higher BP and lower skin temperature values (Fig. 5). With the younger decreased temperature seemed to have only modest effect to the spectral spike amplitudes.

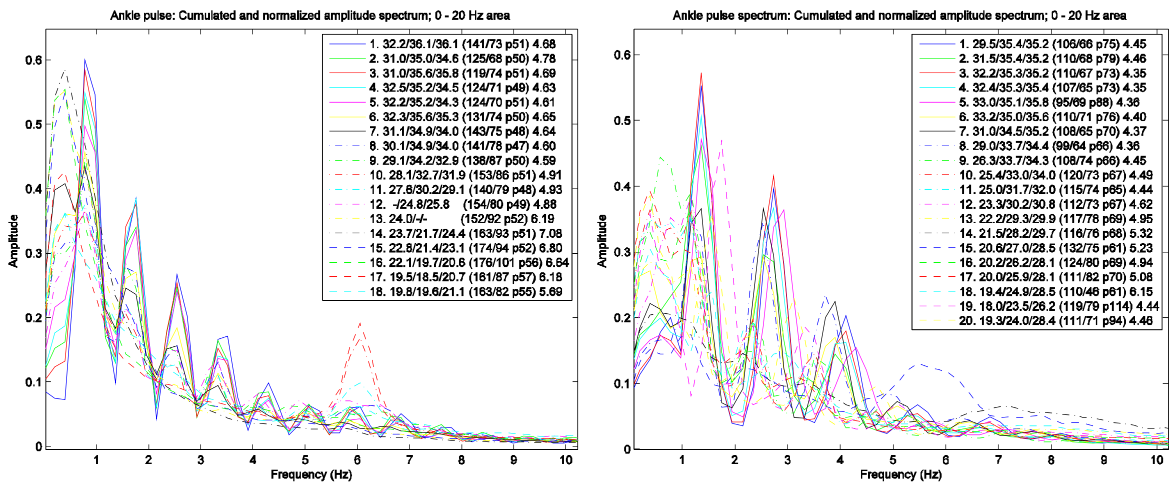

Figure 4. Pulse spectrum from the right ankle pulse from the older (left) and younger person (right) during the cold test. With the older declined temperature decreased spectral spike amplitudes especially in lower frequencies (1 Hz is the HR frequency). Large amplitude spike in 6 Hz (0.17s) appeared, when the systolic BP showed the highest value. The pulse amplitude decrease was seen also in time domain amplitude values (Fig. 8). With the older decreased temperature seemed to have minor effect to spectral spike amplitudes. PWV values from the ankle pulse are depicted after BP value.

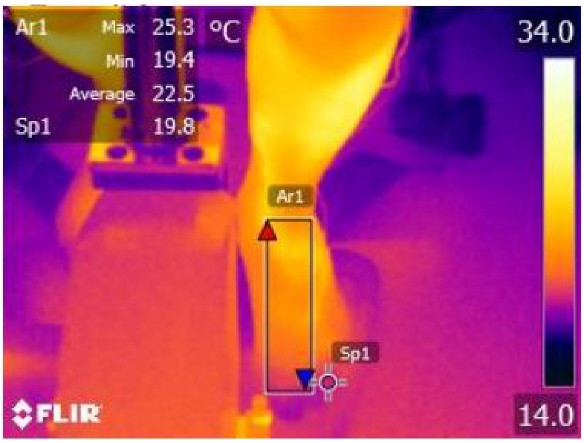

Figure 5. Thermal image from the older person's left foot just before the last measurement (Rec. 18). Although the room temperature started to warm, the temperature of the toe remained low (19.8 C°). The thermal camera was Flir T200.

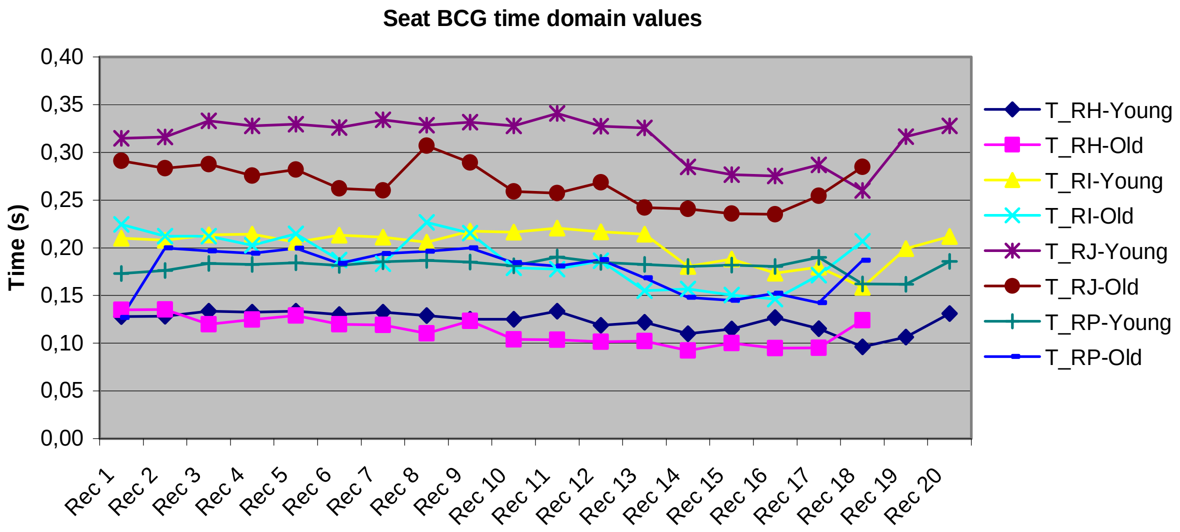

Figure 6. Time domain values in seconds in sitting position from seat BCG and neck pulse signal (T_{RP}) recorded with EMFi sensors from an older and younger person during cold exposure. Temporal values measured from the R wave of the ECG to the corresponding wave point; T_{RH} (tension phase of the ventricles), T_{RI}, T_{RJ}, T_{RP}.

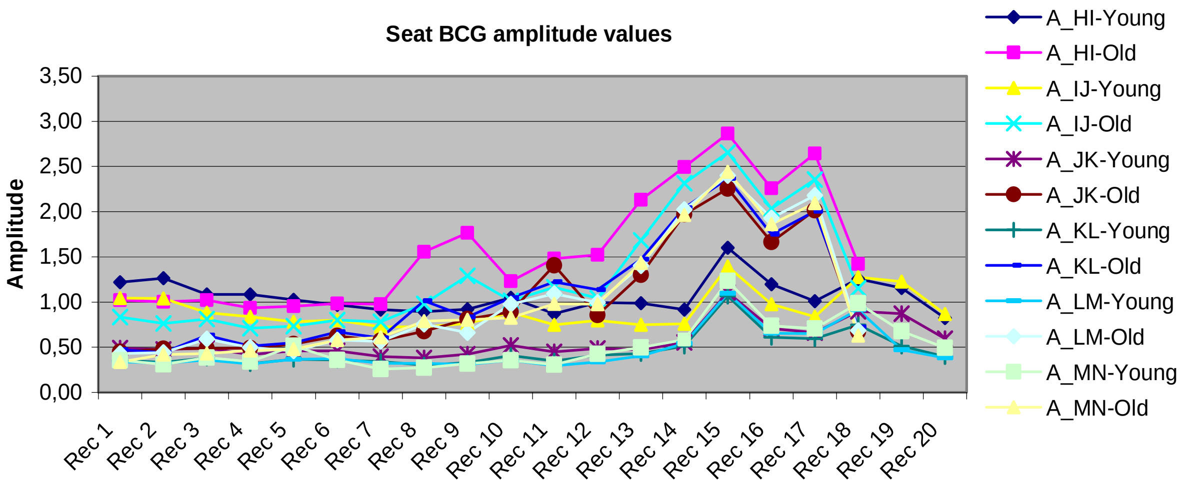

Figure 7. Amplitudes in arbitrary units from an older and younger person during cold exposure recorded with EMFi sensors. A_{HI}, A_{IJ}, A_{JK} are amplitudes of systolic complexes and A_{KL}, A_{LM} and A_{MN} are amplitudes of diastolic complexes. The younger recorded person suffered from intensive shivering during recording (Rec. 15).

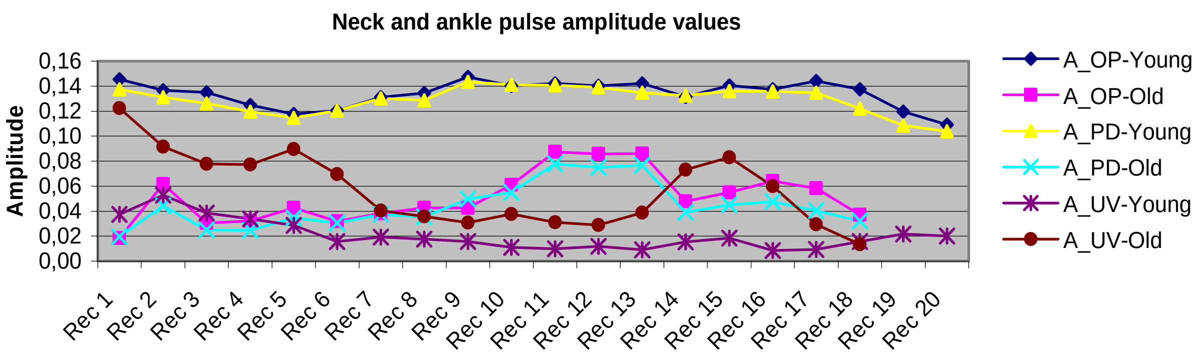

Figure 8. Amplitudes in arbitrary units from an older and younger person during cold exposure recorded with EMFi sensors. A_{OP}, A_{PD} are the neck pulse signal amplitudes and A_{UV} is the ankle signal amplitude. The tightness of the EMFi strip sensor was adjusted on the ankle with the older subject. This caused elevated ankle pulse amplitudes (Rec. 14 – 16) which soon started to decrease steeply.

Discussion

This is the pilot study utilizing by EMFi sensor and controlled temperature environment, where human heart and vasculature reaction was studied by ballistocardiographic means when moving from thermoneutral area to colder side. This study may expose different operation of the body and especially heart-vasculature system between younger and older people during cold exposure. These findings may be related to the cardiovascular mortality peaks during cold winter months, particularly in older adults due to increased workload of the heart. Acute physiological responses were observed, such as BP and HR increase along with marked increase in ballistic amplitude elevations, both in systolic and diastolic amplitudes relating especially to older person. A_{JK} depicting the aortic BP [11] (arterial peripheral resistance) in BCG increased intensively along with the elevation in BP with the older one. With younger person, the A_{JK} increase was moderate as well as rise in BP. With older person, the ankle pulse amplitude A_{UV} decreased during the cold test and failed to return to normal level despite of the cycling in the end of the cold test (Figs. 5, 8). Neither did restore the ankle skin temperature remaining in low value (foot and left hand 19.6 C°).

The ballistic amplitude increase due to cold exposure can be explained by the increased stroke work being more pronounced in older people. Due to reduced efficiency of the heart-vasculature system (decreased elasticity) left ventricular contractility may need to increase in order to maintain stroke volume due to increased afterload during body cooling [10]. Therefore greater systolic pressure formation is needed to cope with the reduced levels of arterial compliance combined with reduced diastolic function with older people [12]. Neck amplitude value A_{OP} was lower with the older person and had more fluctuation when compared to younger person (Fig. 8). As the bloodstream into the central nervous system (head) is closely regulated, changes in neck amplitude values may indicate deviating body regulatory response to the cold exposure. We have earlier shown that signal components of BCG are repeatable in consecutive recordings as well as reproducible in longer time recording intervals [13]. The BCG trace from healthy people has been characterized by a 'considerable distinctness of the waves and a constancy of all the time intervals' [3]. This seemed to be the case also in this study (Fig. 1). As the amount of measured subjects was small, this study serves merely as a method description, how EMFi sensor can be utilized when heart-vasculature system is studied during thermal load with ballistocardiographic means.

The present study indicated clear age-related differences in the circulatory response to a mild whole-body thermal load being more pronounced with the older than the younger subject. As the workload of the heart increased notably due to cold exposure, these findings may underline the importance of the ambient temperature conditions with older people.

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