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Age-related circulatory responses to whole body cooling: observations by heart rate variability

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Abstract

The purpose was to study potential age - related changes in the circulatory system via heart rate variability (HRV) by gradually lowering ambient temperature (0.2°C/min) from thermoneutral (32 C°) towards cold (18 C°). ECG was recorded from a young (31 years) and from an older subject (78 years), both males. During the tests, brachium blood pressure (BP) was recorded.

During the cooling, BP increased in both subjects (young from 95/69 to 132/75 mmHg, old from 125/68 to 176/101 mmHg), the latter exhibiting a prominent rise in diastolic values after cooling. HRV parameters increased in both subjects during the cold exposure being modest in the younger subject as compared to the older one. Also, recovery from the cold in terms of HRV was faster in the younger subject. The present preliminary observations indicate that older age is coupled with altered HRV response to a mild whole-body skin cooling.

Keywords: ECG, heart rate variability, elderly, thermal balance, mild whole-body cooling, blood pressure

Introduction

Heart Rate Variability (HRV) describes the variations of both instantaneous heart rate and RR intervals (interval between consecutive beats) tracing oscillation in consecutive cardiac cycles. It has clinical importance being a strong and independent predictor of mortality following an acute myocardial infarction (MI) [1]. Lower HRV has been correlated with a higher risk of all-cause mortality in survivors of an acute MI and sudden cardiac death. It is associated also with the development of coronary heart disease (CHD) equally in individuals with diabetes. Therefore it has been suggested that HRV could be used as a prognostic factor for MI risk stratification and therapy [2]. HRV has been associated with markers of chronic low-grade inflammation [3]. HRV can be used as an indirect indicator of the autonomic nervous system activity [4]. HRV analysis can be carried out with Kubios [5] (a free software), and it has been used in stress detection [6], obesity research [7] and in fractal analysis of HRV [8].

The arteriovenous anastomoses (AVAs) in hands, feet, toes and fingers take part in the heat exchange with the environment. They are thick-walled vessels between arterioles and venules sited in the deeper layers of the skin being embedded in the subcutaneous fat [9]. Naked, resting human has a thermoneutral zone (comfort zone) at temperatures 27 – 32 C°. In this interval the regulation of skin circulation is sufficient to maintain the stable heat loss during the ambient temperature change. The human core temperature stays at 37 °C. The skin insulation properties improve, 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 per second. During muscle constriction muscles constrict simultaneously; 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 increase manyfold in few seconds. The body temperature decrease below 25 °C increases mortality risk and may lead to ventricular fibrillation [10]. Myocardial infarction and cardiovascular (CV) related mortality increase at low outdoor temperature [11]. The main goal of this study was to analyse ECG:s HRV changes by studying temporal and spectral differences between measured subjects during mild whole body cooling.

Methods and measurements

In this paper a Mobile Physiological Signal Measurement Station has been used in recording ECG [12]. The test included temperature changes from thermoneutrality to cold. This study was carried out 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. ECG signal was recorded from two subjects, young (31 years; 20 recordings) and old subject (78 years; 19 recordings), in a sitting position having a minimal clothing (shorts). At the end of recordings there was also added cycling in order to restore the inner temperature of the studied subject. ECG signal from electrodes was first amplified and DC level filtered out in the measurement device [12], and then directed into a notebook computer having a data acquisition card (Daqcard 6036E). The signals were converted into ASCII format. Each measurement lasted for 5 min and the sampling frequency was 500 Hz. Unfiltered ECG signals were directed into a Kubios HRV software [5] for HRV analysis. Fast Fourier Transform (FFT) was employed for its effectiveness [13].

Time domain measures of HRV were selected as SDNN (standard deviation of all NN inter-vals), RMSSD (the square root of the mean of the sum of the squares of differences between adjacent NN intervals), all in milliseconds. Heart rate (HR) and standard deviation of HR were also selected. For frequency measures of HRV were chosen VLF (Very low frequency), LF (Low frequency) and HF (High frequency) power (ms2) [1]. Just before the measurements the blood pressure and the pulse were recorded with Omron M5-I BP monitor device. Matlab software was used to plot ECG spectrum from all recordings in order to trace changes of consecutive recordings in spectral plane. ECG amplitude spectrum was calculated from raw signal, cumulated (by adding current spectrum value to amplitude scaled value) and normalised.

Results

When obtained ECG recordings (analysed with Kubios HRV software) were compared between young and old subject, notable HRV parameter elevations were detected, especially, with the old subject. This was especially clear in recordings from the coldest ambient temperature. HR and STD of HR increased; large increases in SDNN, RMSSD and FFT spectrum VLF, LF and HF power (ms^2) values were observed. HRV parameters increased considerably within the old subject when cooling (Table 1, Fig. 1) depicting the increased work-load of the heart due to coldness. Smaller FFT power spectrum changes were observed with the younger subject when propagating to cold side (Table 2, Fig. 2). Advancing spectral changes were seen with both subjects when cooling proceeded (Fig. 3). BP elevated in both subjects when cooling being higher in the old one (Table 1) and lower in the young (Table 2). Systolic BP values seemed to rise more than diastolic BP values. HR values had prominent increase in the old and modest increase in the young subject while cooling.

Table 1. ECG HRV values from the old subject obtained from the Kubios HRV program. Amb. T is ambient temperature in the thermal chamber. HR is the mean heart rate and STD is the standard deviation of HR. BP is the blood pressure and pulse values from Omron M5-I BP monitor device. The old subject shivered due to cooling in recordings 13 to 15. He shivered also during recording 16, after a short cycling period. Before recordings 18 and 19, cycling had lasted about 5 min. During cycling the subject sat on the measurement chair and the purpose of cycling was to restore the inner temperature of the studied subject.

	SDNN	RMSSD	VLF	LF	HF	LF/HF	HR/STD HR	BP	Amb.T
Rec 1	8.9	14.0	6	19	44	0.440	51.4/0.46	141/73 p.51	-
Rec 2	9.1	13.6	2	22	39	0.557	50.6/0.46	125/68 p.50	-
Rec 3	30.6	48.9	3	14	91	0.158	50.7/2.03	119/74 p.51	-
Rec 4	9.3	14.2	8	24	35	0.697	51.1/0.57	124/71 p.49	-
Rec 5	8.4	14.2	1	10	35	0.277	51.3/0.44	124/70 p.51	28.7
Rec 6	11.8	18.7	6	30	64	0.465	50.5/0.62	131/74 p.50	29.0
Rec 7	11.9	16.5	13	33	56	0.600	49.5/0.70	143/75 p.48	26.0
Rec 8	18.0	28.2	8	89	297	0.299	49.8/0.97	141/78 p.47	23.0
Rec 9	10.6	16.8	10	36	59	0.605	48.6/0.54	138/87 p.50	23.0
Rec 10	11.7	19.3	5	13	67	0.198	49.0/0.55	153/86 p.51	23.0
Rec 11	14.1	22.6	3	35	82	0.430	49.1/0.65	140/79 p.48	21.0
Rec 12	13.4	21.3	5	45	89	0.512	49.1/0.63	154/80 p.49	19.3
Rec 13	15.1	21.5	12	50	86	0.581	50.6/0.83	152/92 p.52	18.6
Rec 14	54.1	82.7	286	4154	4718	0.880	50.7/1.55	163/93 p.51	17.0
Rec 15	55.8	83.6	174	3321	3667	0.906	52.1/1.67	174/94 p.52	16.0
Rec 16	16.3	24.2	17	58	130	0.450	54.6/0.95	176/101 p.56	16.0
Rec 17	15.1	23.2	8	36	135	0.267	55.3/1.02	161/87 p.57	17.3
Rec 18	42.3	66.2	19	178	677	0.264	55.9/4.08	163/82 P.55	17.0
Rec 19	10.8	15.5	5	21	54	0.379	55.4/0.75	148/88 p.55	-

Table 2. ECG HRV values from the young subject obtained from the Kubios HRV program. In recording 6 hands started to shiver, followed by more intensive shivering in recording 8 and leading to continuous shivering during recording 13. 5 min cycling was done before recording 18 and during recording 18 the measurement room started to warm up.

	SDNN	RMSSD	VLF	LF	HF	LF/HF	HR/STD HR	BP	Amb.T
Rec 1	21.0	13.3	13	270	45	5.97	82.2/2.67	106/66 p.75	-
Rec 2	29.7	20.4	64	725	227	3.19	79.1/3.77	110/68 p.79	-
Rec 3	25.2	16.1	39	301	90	3.35	81.4/3.05	110/67 p.73	-
Rec 4	29.0	20.2	35	626	173	3.61	81.0/3.52	107/65 p.73	-
Rec 5	30.3	17.4	31	490	173	2.83	85,1/3.91	95/69 p.88	28.7
Rec 6	40.6	24.5	163	713	193	3.70	77.9/5.41	110/71 p.76	29.0
Rec 7	21.0	14.2	23	295	50	5.94	77.3/2.48	108/65 p.70	26.0
Rec 8	23.9	17.8	39	394	134	2.95	75.3/2.75	99/64 p.66	23.0
Rec 9	16.7	15.8	13	146	73	1.99	72.1/1.90	108/74 p.66	23.0
Rec 10	22.7	20.9	55	361	107	3.37	70.0/2.61	120/73 p.67	23.0
Rec 11	23.2	20.4	38	233	110	2.12	68.7/2.56	115/74 p.65	21.0
Rec 12	22.9	23.1	11	412	138	2.98	69.0/2.32	112/73 p.67	19.3
Rec 13	26.1	24.9	51	468	219	2.13	68.6/2.58	117/78 p.69	18.6
Rec 14	26.1	22.7	12	412	129	3.20	68.9/2.50	116/76 P.68	17.0
Rec 15	43.2	34.7	84	964	362	2.67	68.6/4.57	132/75 P.61	16.0
Rec 16	29.2	27.1	89	246	247	0.99	68.4/2.75	124/80 P.69	16.0
Rec 17	31.9	28.1	79	890	304	2.93	67.5/3.25	111/82 P.70	17.3
Rec 18	25.6	14.5	66	296	36	8.17	89.4/4.17	110/46 p.61	17.0
Rec 19	14.8	8.1	13	104	12	8.68	103.5/2.99	119/79 p.114	17.5
Rec 20	22.5	12.9	15	388	65	6.00	93.6/3.51	111/71 p.94	18.0

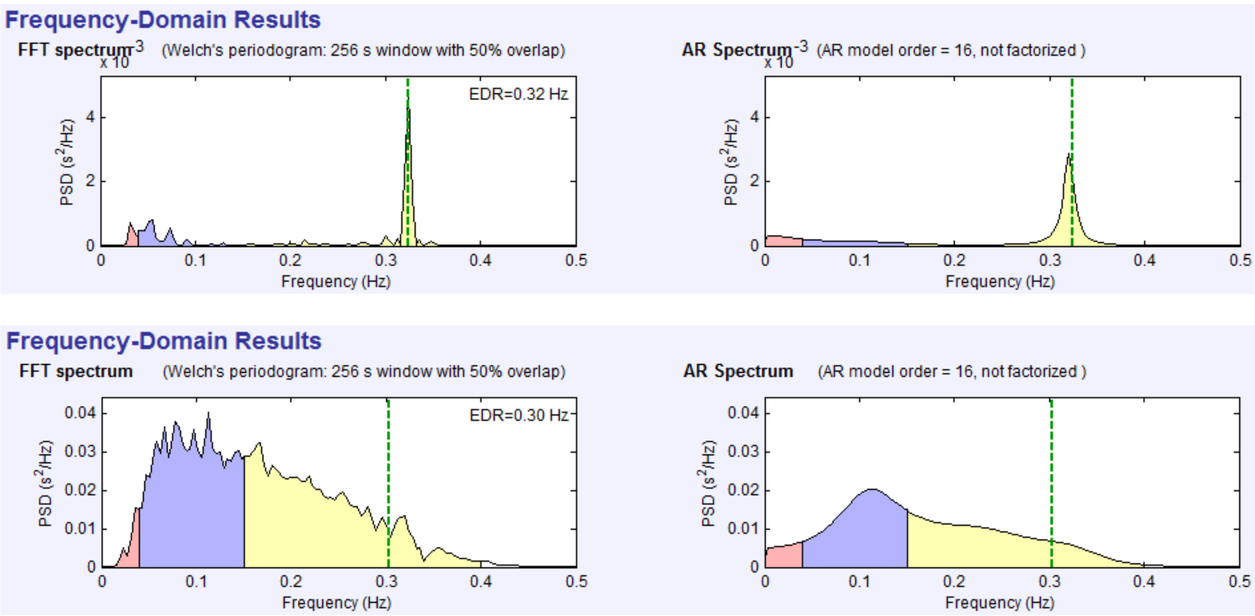

Figure 1. FFT spectrum results from the Kubios program from the old subject. Pink coloured area: VLF frequency area (0 - 0.04 Hz); blue: LF frequency area (0.04 - 0.15 Hz); yellow: HF frequency area (0.15 - 0.4 Hz). Upper picture is from recording 1 (Table 1) related to neutral temperature situation (Spectral amplitude $4 \cdot 10^{-3} = 0.004$ in the

upper picture). Lower picture depicts recording 15 with the lowest ambient temperature and before cycling. When compared to neutral ambient temperature situation, at 16 °C, the power of the FFT spectrum increased considerably depicting the increased workload of the heart due to coldness.

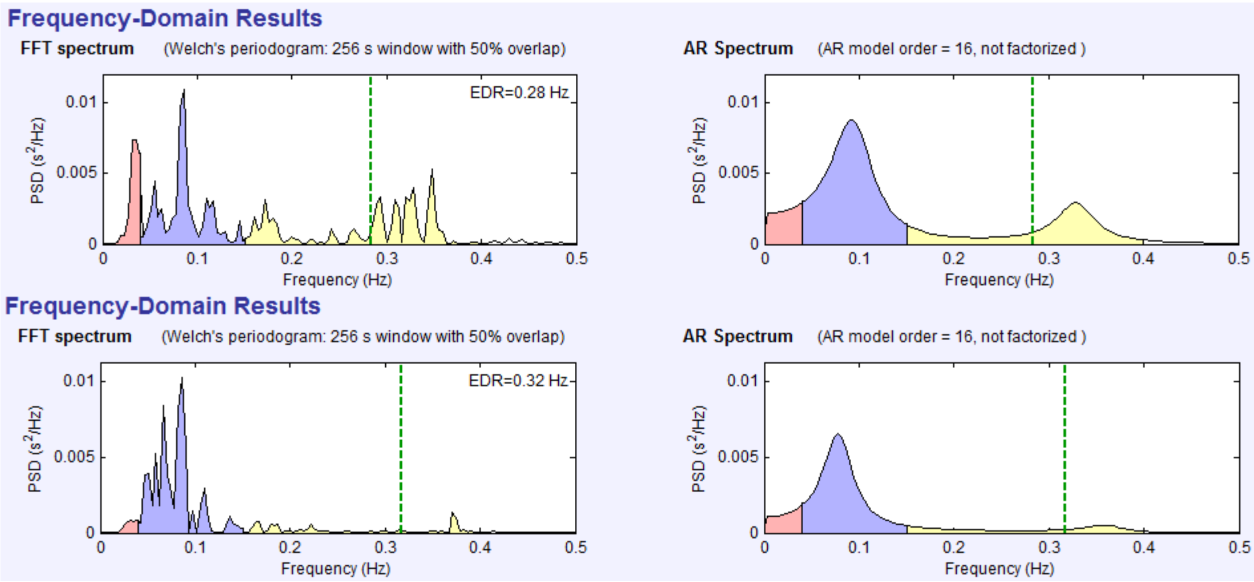

Figure 2. FFT spectrum results from the Kubios program from the young subject. Pink coloured area: VLF frequency area (0 - 0.04 Hz); blue: LF frequency area (0.04 - 0.15 Hz); yellow: HF frequency area (0.15 - 0.4 Hz). Upper picture is from recording 1 that was related to neutral temperature situation. Lower picture depicts recording 16 (Table 2) with the lowest (16 °C) ambient temperature. HRV has a natural frequency around 0.1 Hz differing slightly from person to person. In normal HRV spectrum originating from the activity of normal physiological control systems: A temperature component in the region of 0.05 Hz, blood pressure component at around 0.1 Hz followed by a respiratory component at near 0.25 Hz depending on the respiratory rate [15]. Temperature drop with the young subject induced modest changes in FFT spectrum suggesting better adapting ability of the heart-vasculature system to coldness.

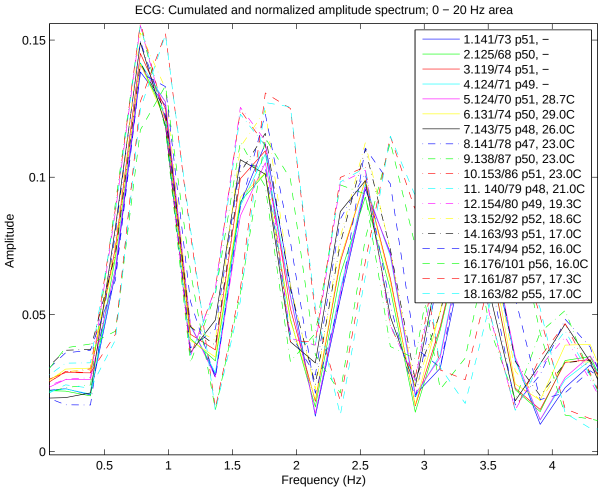

Figure 3. Amplitude spectra from the old subject on the left and from the young subject on the right picture. The first spectral spike is the heart rate frequency; 0.9 Hz in the old and 1.2 Hz in the young subject. When cooling, the heart rate increased, shown as movement of the spectral spikes to higher frequencies. Visually higher spectral variation can be seen on the right side picture from the young subject.

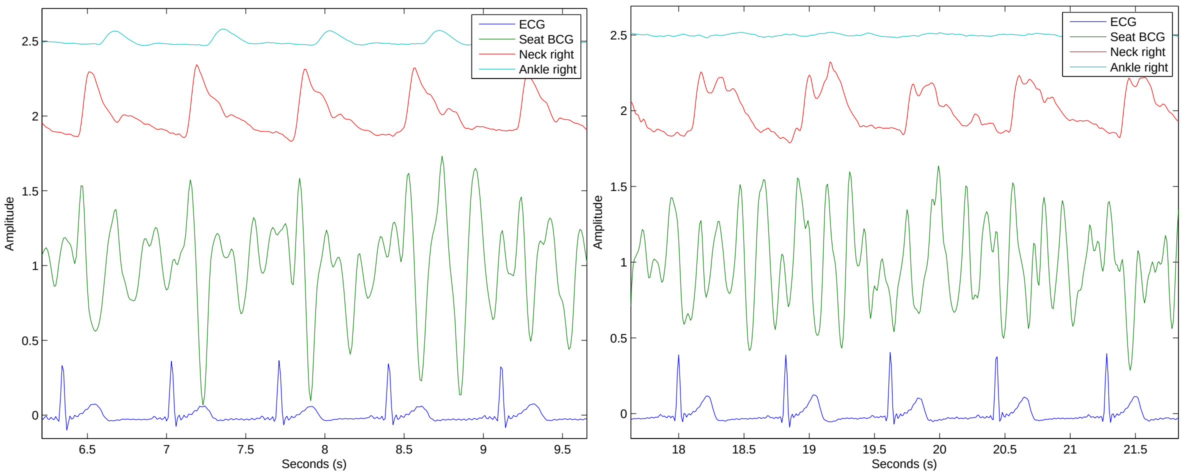

Figure 4. Time domain values including ECG from the young subject. The left side picture is from recording 1 (thermoneutrality) and the right side picture is from recording 16 denoting the lowest ambient temperature (16 C). Other signals are described in [14]. The ambient cooling changed slightly the shapes of the signals, especially, the form of the pulse signal from the neck changed, possibly due to increased aortic stiffness (the second 'spike' in the aortic pulse trace). Body cooling increased aortic BP, increased aortic pulse wave velocity and changed the shape of the aortic pulse trace due to the returning pulse wave from the lower body.

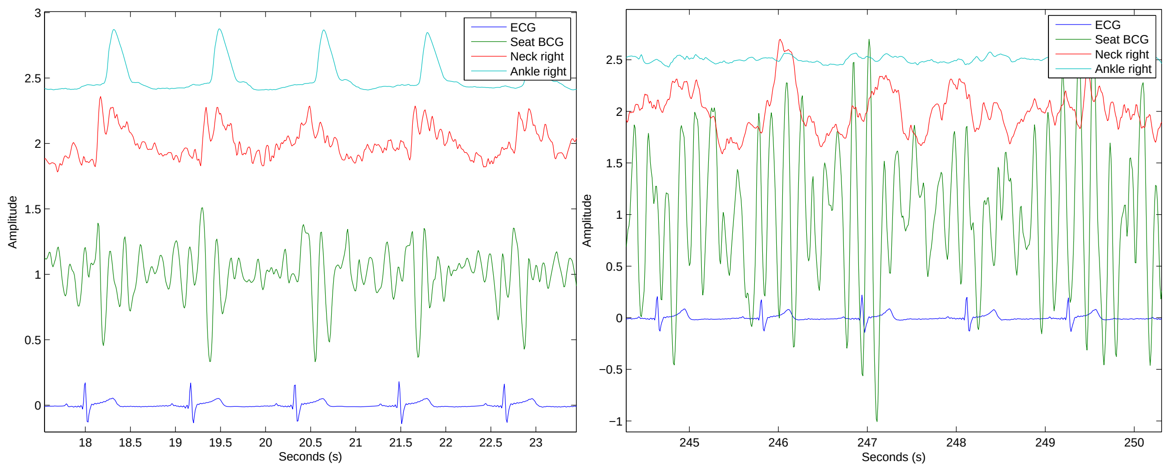

Figure 5. Time domain values including ECG from the old subject. The left side picture is from recording 1 (thermoneutrality) and the right side picture is from recording 15 denoting the lowest ambient temperature (16 C). Other signals are described in [14]. Ambient coldness increased strongly the amplitudes of the recoil forces of the heart (Seat BCG signal). Ankle signal amplitude (Ankle right) almost vanished as the body cooling decreased the blood circulation in the extremities in order to maintain the core temperature.

Discussion

In this experiment, we studied circulatory response to age-related mild whole-body cooling by utilizing the HRV of the ECG. Usually higher HRV is better than the lower one and when the young and old subject's obtained HRV parameters were compared in the thermoneutral area, then the young subject had more HRV (Tables 1, 2). During cold exposure the HRV parameters increased in both subjects, but the increase was more modest in the young individual. In the old subject during the lowest ambient temperature, the rise in FFT spectrum components was so high, that the results seemed more like artefacts. During the coldest ambient temperature ballistic recoil forces of the heart-vasculature system increased strongly in the old subject and were more lenient in the young one (Figures 4, 5) [14]. The young subject started to shiver earlier and the shivering lasted longer compared to old subject. This may imply better adaptation ability of the heart-vasculature system (better aortic elasticity) to extreme conditions, like ambient coldness in the young subject.

The HRV results of this study support our earlier study [14] from the same measurement data in the same environmental conditions indicating clear age-related differences in heart-vasculature system as a response to a mild whole-body thermal challenge. In our earlier study EMFi- sensor was utilized in recording ballistocardiographic recoil movements of the heart and vasculature system (ballistocardiography) when moving from thermoneutrality to cold. Notable amplitude elevations of the ballistic recoil movements were noticed especially in the old subject, and the increase of aortic pulse wave velocity (PWV) values reflected closely BP meter values under cooling. In the literature there is very little data on HRV after whole-body cold stress. Whole body cryotherapy (WBC) has been studied, but it did not show significant change in HRV during the three months [4].

This study improves the understanding of the variation in the body function, especially, in cardiovascular system between young and old populations during cold exposure. These findings can be correlated 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 HRV parameters being especially relevant to elderly.

The present study indicated clear age-related differences in the ECG:s HRV response to a mild whole-body thermal load being more pronounced in the old than in the young subject. As the workload of the heart increased notably due to cold exposure, these findings may underline the importance of the consideration of the ambient temperature conditions for old people.

References

[1] 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 1996;17(3):354-381.

[2] Liao D, Carnethon M, Evans GW, Cascio WE, Heiss G. Lower heart rate variability is associated with the development of coronary heart disease in individuals with diabetes: the atherosclerosis risk in communities (ARIC) study. Diabetes 2002;51(12):3524-3531.

[3] Jensen MT, Marott JL, Allin KH, Nordestgaard BG, Jensen GB. Resting heart rate is associated with cardiovascular and all-cause mortality after adjusting for inflammatory markers: The Copenhagen City Heart Study. Eur J Prev Cardiol 2012;19(1):102-108.

[4] Westerlund T. Thermal, Circulatory, and Neuromuscular Responses to Whole-body Cryotherapy [Doctoral Thesis]. Acta Universitatis Ouluensis. Series D, Medica (1006). Faculty of Medicine, Institute of Biomedicine, Dept of Physiology, University of Oulu; 2009

[5] Tarvainen MP, Niskanen JP, Lipponen JA, Ranta-aho PO, Karjalainen PA. Kubios HRV - Heart rate variability analysis software. Comput Methods Programs Biomed 2014;113(1):210-220.

[6] Melillo P, Bracale M, Pecchia L. Nonlinear Heart Rate Variability features for real-life stress detection. Case study: students under stress due to university examination. Biomed Eng Online 2011;10:96. doi: 10.1186/1475-925X-10-96.

[7] Criado JR, Gilder DA, Kalafut MA, Ehlers CL. Obesity in American Indian and Mexican American men and women: associations with blood pressure and cardiovascular autonomic control. Cardiovasc Psychiatry Neurol 2013;2013:680687. doi: 10.1155/2013/680687.

[8] Cardoso MA, Dos Santos AM, etc. Fractal scaling exponents of heart rate variability association with linear indices and Poincare Plot. Exp Clin Cardiol 2014;20(1):2444-2456.

[9] Vanggaard L, Kuklane K, Holmer I, Smolander J. Thermal responses to whole-body cooling in air with special reference to arteriovenous anastomoses in fingers. Clin Physiol Funct Imaging 2012;32(6):463-469.

[10] Sand O, Sjaastad OV, Haug E, Bjalie JG. Ihminen. Fysiologia ja anatomia. Sanoma Pro; 2011. p. 444-449.

[11] Hess KL, Wilson TE, Sauder CL, Gao Z, Ray CA, Monahan KD. Aging affects the cardiovascular responses to cold stress in humans. J Appl Physiol (1985). 2009;107(4):1076-1082. doi: 10.1152/japplphysiol. 00605.2009.

[12] Alametsä J, Värri A, Viik J, Hyttinen J, Palomäki A. Ballistocardiogaphic studies with acceleration and electromechanical film sensors. Med Eng Phys 2009;31(9):1154-1165.

[13] Kamath MV, Watanabe MA, Upton A. editors. Variability (HRV) Signal Analysis. Clinical Applications. CRC Press; 2012

[14] Alametsä J, Smolander J, Vanggaard L, Halder A, Lundgren K, Gao C et al. Age-related circulatory responses to whole body cooling and warming: observations by ballistocardiographic EMFi sensors. In: Proceedings of the Ambience14&10i3m, Scientific Conference for Smart and Functional Textiles, Well-Being, Thermal Comfort in Clothing, Design, Thermal Manikins and Modelling, 7-9 September 2014, Tampere, Finland.

[15] Koskinen T. Heart rate variability in young adults - Reference values and associations with cardiometabolic risk factors and vascular properties. The Cardiovascular Risk in Young Finns Study. [Doctoral thesis]. Department of Clinical Physiology and Isotope Medicine, Institute Clinical Medicine, Faculty of Medicine, Doctoral Programme of Clinical Investigation, and Research Centre of Applied and Preventive Cardiovascular Medicine, University of Turku, Turku, Finland and Turku University Hospital. Annales Universitatis Turkuensis, Medica-Odontologia, Turku, Finland, 2014.