Original article

Gender-related specificities of photoplethysmogram spectral assessment dynamics in healthy subjects during the passive tilt test

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Abstract: The *goal* of our study was to investigate gender-related specificities of photoplethysmogram (PPG) spectral assessment dynamics in healthy individuals during the passive tilt test.
Material and Methods — The study involved 38 men (33±7 years old) and 15 women (27±8 years old). The PPG signal was recorded for 10 minutes in the horizontal and vertical positions of the human body (passive tilt test). The following spectral parameters of PPG were calculated: HF%, LF%, and LF/HF.
Results — In the horizontal body position, men had significantly higher values of the LF% index. In the course of the passive tilt test, an increase in HF% was observed by almost 1.5 times in men and by more than 5 times in women. Significant differences in the values of vegetative indicators were achieved: in women, HF% values exceeded those in men, while LF% values were noticeably lower.
Conclusion — Men displayed signs (assessed by LF%) of augmented sympathetic activity, relative to women, at all stages of their passive tilt test. During the transition from the horizontal to the vertical position, a significant increase in respiratory influences (assessed by HF%) on PPG signal components was established, which was more pronounced in women.

Keywords: gender-related specificities, autonomic regulation, photoplethysmogram, cardiovascular system.

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Introduction

The study of interactions among various oscillatory processes in the human cardiovascular system has been attracting an attention of scientists for many years [1, 2]. The study of the principles of regulatory processes interaction, manifested in the form of distal vascular bed oscillations, is of great fundamental and applied importance, allowing to indirectly evaluate the autonomic nervous system functioning.

It is known that there are oscillations at a frequency of about 0.1 Hz in the basic heart rhythm (isolated from the RR intervals of the electrocardiogram) and peripheral vascular bed. These oscillations actively interact with each other and tend to synchronize [3]. It is assumed that synchronization degree of these oscillations, along with a presence and direction of connections between oscillations in heart rhythm and peripheral vascular bed, can be one of the quality indicators of the cardiovascular system autonomic regulation [3]. Previously, we have already conducted a study on the interactions of oscillatory processes in healthy individuals during a functional fitness test. We analyzed the interactions between oscillations in heart rate variability, peripheral vascular bed and respiration in different frequency ranges: high frequency (HF; 0.14-0.40 Hz) and low frequency (LF; 0.04-0.14 Hz). The identified complex cardiorespiratory interactions have demonstrated a decline in the average coherence level, as well as a change in the structure of directional connections between fluctuations in the LF and HF ranges in respiration, heart rate, and peripheral blood flow, which characterized the properties of adaptive processes in the cardiovascular system [4].

Besides, in addition to the described methods, for an indirect assessment of the autonomic regulation functional activity *via* spectral analysis of the distal vascular bed oscillations, there is also the method of a digital photoplethysmography [5]. Previously mentioned high-frequency (HF) and low-frequency (LF) oscillations in the photoplethysmogram (PPG) signal are of particular interest, since they show their potential for the clinical practice [6]. The genesis of HF oscillations is traditionally associated with the mechanical effect of respiration on the peripheral blood flow [7]. LF oscillations are present in various cardiovascular system processes, such as heart rate, arterial pressure and peripheral blood flow [8]. LF oscillations in the heart rate and arterial pressure are caused by the properties of baroreflex regulation [9], along with sympathetic modulation of peripheral vascular tone [7, 10]. Natural myogenic oscillations of the vascular wall in the microvasculature vessels [11] and oscillations of blood filling in the distal arteries contribute to similar oscillations in PPG [12]. At the same time, the functional autonomy of LF oscillations in the heart rhythm and peripheral blood flow, assessed by the PPG signal, is shown in some studies [13]. We should also mention the hormonal status influence of men and women in different periods of their lives on the indices of autonomic regulation of blood circulation, assessed primarily by heart rate variability [14]. However, the gender-related specificities of the assessments of autonomic nervous system status, obtained by the spectral analysis of the PPG signal, have not yet been specified.

In the clinical practice, the proper standard for diagnosing autonomic regulation disorders, as well as assessing the adaptive reserves of the human body, is achieved by conducting functional tests, for example, a passive tilt test [15]. Hence, the goal of our study was to investigate the properties of the cardiovascular system autonomic regulation in healthy individuals by analyzing the spectral characteristics of the PPG signal during the passive tilt test.

Material and Methods

The study encompassed 53 apparently healthy individuals 20 to 50 years old: 38 men (33±7 years) and 15 women (27±8 years). Criteria for inclusion of the subjects in the study were their written informed consent, ages of 20-50, and absence of pathologies of all organs and systems.

In all subjects, the PPG signal was recorded in transmitted light during 10 min by a PPG sensor placed on a distal phalanx of the right-hand middle finger. Signals were recorded in two positions of the human body: horizontal and vertical (passive tilt test). All studies were carried out under standard conditions: in a dark room, with spontaneous breathing (absence of forced breathing and breath holding during the registration). To exclude the influence of circadian factors, signals were recorded over the time interval from 15 to 16 hours. Signals were recorded using a multichannel electroencephalograph-analyzer EEGA-21/26 Encephalan-131-03, model 10 (Medicom-MTD, Russia), with a set of standard sensors with a frequency of 250 Hz at a 12-bit resolution.

The analysis included recordings of PPG signals without interference, extrasystoles, noticeable linear trend, and transient processes. The signals were filtered in the 0.04–0.4 Hz band. The following indicators were analyzed: HF% (high-frequency band, 0.15–0.4 Hz, in percentage of total spectral power, 0–0.4 Hz); LF% (low-frequency band, 0.04–0.15 Hz, in percentage of total spectral power, 0–0.4 Hz); and LF/HF ratio.

Statistical analysis was performed using Microsoft Office Excel 2007 (Microsoft, USA) and STATISTICA 6.0 (StatSoft Inc., USA). Quantitative variables are presented in form of a mean with standard deviation, M±SD, for normally distributed data, or as a median with lower and upper quartiles, Me (LQ, UQ) for distributions other than normal. For quantitative variables, the statistical significance of differences between the groups was assessed using the Mann-Whitney U test. The differences were considered significant at $p<0.05$.

Results

Analysis of PPG signals, regardless of body position, revealed some gender specificities. For example, in the horizontal body position in men, unlike women, statistically significantly higher values of the LF% were discovered. A similar trend was observed when assessing the LF/HF ratio. When analyzing the HF% index, men exhibited lower values than women, although the differences were not statistically significant (*Table* 1).

The passive tilt test demonstrated general trends for both men and women. There was a statistically significant increase in HF% by almost 1.5 times in men and over 5 times in women. Besides, we observed an insignificant increase in LF% ($p>0.05$) and decrease in the LF/HF value (1.3 times in men and over 16 times in women) (*Table* 2). As for a vertical body position, gender-related differences were also uncovered in the achieved levels of autonomic indicators: in women, HF% values exceeded those in men, while LF% values were noticeably lower (*Table* 1).

Discussion

The presented results reflect the gender-related contribution of various regulatory processes to the formation of variability in peripheral blood flow in healthy people. Studying and analyzing these processes constitute an important clue for understanding the biophysical foundations of the regional blood circulation physiology in terms of participating central and local regulatory mechanisms.

Table 1. Comparison of the PPG signal spectral parameters in men versus women during the passive tilt test

Parameters	Horizontal body position			Vertical body position		
	Men	Women	p	Men	Women	p
HF%	9.6 (5.0, 14.7)	13.4 (3.3, 61.2)	0.693	13.14 (8.2, 44.3)	69.5 (17.7, 82.3)	0.026
LF%	53.1 (37.5, 61.7)	14.4 (8.0, 34.9)	0.003	54.85 (21.7, 62.5)	17.5 (9.3, 50.1)	0.029
LF/HF	5.1 (1.8, 8.6)	4.4 (0.3, 6.2)	0.161	3.93	0.27	0.025

Table 2. Intragroup dynamics comparison of the PPG signal spectral parameters during the passive tilt test

Parameters	Men			Women		
	HP	VP	p	HP	VP	p
HF%	9.6 (5.0, 14.7)	13.14 (8.2, 44.3)	0.029	13.4 (3.3, 61.2)	69.5 (17.7, 82.3)	0.040
LF%	53.1 (37.5, 61.7)	54.85 (21.7, 62.5)	0.901	14.4 (8.0, 34.9)	17.5 (9.3, 50.1)	0.694
LF/HF	5.1 (1.8, 8.6)	3.93	0.205	4.4 (0.3, 6.2)	0.27	0.141

HP, horizontal body position; VP, vertical body position.

In our study, when assessing the contribution of LF oscillations to the PPG signal in the supine position, it was established that it was higher in men than in women. However, when moving to a vertical position, the increase of this indicator in both men and women was insignificant. At the same time, the contribution of HF oscillations, primarily characterizing the mechanical effect of respiration, was increasing in both groups.

It is well known that, when the body moves from a horizontal to a vertical position, blood, under the influence of gravity, rushes to the lower sections and is accumulated largely in the venous bed of the lower extremities and internal organs [16]. A decline in central venous pressure leads to a decrease in the blood filling of the heart cavities and, as a consequence, to a reduction in the stroke volume of blood [17]. According to the literature, the normal time for blood redistribution is about 10-15 seconds [18]. In healthy people, these processes persist for 30-60 seconds [19] and are subsequently compensated by a number of mechanisms [20, 21], one of which is an increase in the sensitivity of carotid baroreceptors [17]. Reduced stretching and inactivation (unloading) of baroreceptors leads to vasoconstriction of the vessels in the abdominal organs [22] and to passive elastic recoil of accumulated blood in the lower extremities and abdominal organs, which partially compensates for the loss of central blood volume [23]. Weakening the effect on cardiopulmonary baroreceptors also promotes reflex vasoconstriction [24]. Blood pressure decrease usually occurs solely during a temporary mechanical imbalance of initial hypotension. After that, both systolic pressure and diastolic blood pressure, as a rule, increase slightly compared with the supine position. Despite the constant or even augmented blood pressure, increased sympathetic activity persists, which once again indicates the importance of the cardiopulmonary reflex [21].

There is evidence that diastolic blood pressure correlates, to a greater extent, with the activity of the muscle sympathetic nerve [25] and, during a change in body position, has a tendency to a more pronounced increase in its values in comparison with systolic blood pressure [21]. Besides, we are aware of the dynamic relationship between the phases of respiration and the activity of the autonomic nervous system: an increase in the activity of the muscle sympathetic nerve at the end of expiration, its decrease at the end of inspiration [26], accompanied by a simultaneous increase in diastolic pressure during this phase [27]. These interrelationships may be caused by functionally unified mechanisms of autonomic control of the respiratory and cardiovascular systems [28, 29].

As noted earlier, HF oscillations are associated with passive respiratory effects on the peripheral vascular bed [5]. Taking into account that the process of respiration in the peripheral bloodstream is associated, to a greater extent, with the venular bed, it is quite logical to expect a more pronounced increase in the values of HF oscillations (under an increase in diastolic pressure) with a relatively less pronounced surge in the values of LF oscillations in the process of adaptation to a body position change. Also, higher contribution of LF oscillations to the formation of the PPG spectrum at rest in men, relative to women, may be caused by an increased activity of the muscle sympathetic nerve [30].

When comparing the LF% and HF% indicators in men and women in an upright position, we found significant differences in both indicators. We assumed that this phenomenon could be caused by the peculiarities of the humoral regulation mechanisms, which could be tested in a further study.

The major limitation of our study was due to relatively small sample sizes of the groups. However, the obtained results achieved the required level of statistical significance, making it possible to consider sample sizes of groups sufficient for fulfilling the study goal.

Conclusion

In the course of our study, we identified gender specificities in the frequency components distribution of the PPG signal during the passive tilt test in healthy people. Men showed signs (assessed by the LF%) of augmented sympathetic activity, relative to women, at all stages of the test. During the transition from the horizontal to the vertical position, a significant increase in respiratory influences (assessed by HF%) on the PPG signal components was revealed, which was more pronounced in women.

Conflict of interest

The study was conducted as a part of fulfilling the R&D on the topic, ‘Developing the Technology for Screening Health Status Based on the Assessment of Nonlinear Biophysical Properties of Blood Circulation Regulatory Processes for Primary Prevention of Chronic Cardiovascular Diseases’ at State Medical University of Saratov in compliance with the Government Procurement of the Ministry of Healthcare of Russian Federation for 2019-2021.

Ethical approval

The study design was approved by the Ethics Committee at State Medical University (Saratov, Russia).

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