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Original article

Features of the relationship between postural balance indicators and heart rate variability in elderly women with falls syndrome

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Abstract: *Objective* — The goal of our study was to establish the relationship between the postural balance and heart rate variability (HRV) in elderly women with the falls syndrome.
Material and Methods — The study was conducted on120 women aged 60-74 YO. The study group included women with the falls syndrome who experienced two or more falls during the year (n=60), while the comparison group consisted of women without falls (n=60). Postural balance assessment was performed via the computerized stabilometric complex *Balance Master®*, NeuroCom, Natus Medical, USA. The state of autonomic nervous system was assessed by cardiointervalography using the *VNS-Spectrum* computer appliance (Neurosoft, Russia).
Results — The matrix of intersystem correlations between indicators of postural balance and HRV in women with the falls syndrome was characterized by a small number of statistically significant correlations (6.25%). Same was true for the control group (10.85%). The correlations were noted in the Sit to Stand, Tandem Walk, and Step Up and Over tests in elderly women with the falls syndrome, while in the control group, they were observed only in the Step Quick Turn test.
Conclusion — Features of the relationship between postural balance indicators and HRV in elderly women with the falls syndrome were characterized by a worse coordination of intersystem interactions of HRV indicators with indicators of the performance quality of complex motor acts and power indicators of postural balance, as compared with the elderly women without falls syndrome.

Keywords: postural balance, heart rate variability, falls syndrome, women, elderly.

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Introduction

Most of the motor acts performed by people as part of their daily routine are under cognitive control, which allows the central nervous system implementing continuous advanced postural adjustments, especially in problematic situations when the postural balance system encounters an external disturbing factor that leads to a shift in the center of body mass relative to the support base [1-4].

Postural stability depends primarily on the coordinated functioning of physiological mechanisms ensuring vertical stability, involving the musculoskeletal system, several sensory systems, and the nervous system. At the same time, the development of compensatory postural adjustments occurs very rapidly, between 80-120 ms after the disturbance [5-7]. Compensatory postural adjustments occur automatically, without the participation of a volitional component, and despite the extremely rapid time of their occurrence, these reactions are very precise and include analysis of the environment, for example, the use of a handrail to restore balance.

The extremely high rate of implementation of compensatory postural adjustments indicates that they occur at subcortical levels under the modulating influence of higher cortical centers [8, 9]. It is also worth emphasizing that a change in vertical stability can be considered as a condition that threatens the individual. Accordingly, the human body regards this as a stressful situation requiring an immediate response. Likewise, the autonomic nervous system and its sympathetic division in particular are habitually associated with the implementation of fight-or-flight responses during stressful situations.

Sympathetic responses to immediate imminent stress include increased heart rate, vasoconstriction, redirection of blood flow to skeletal muscles, dilated pupils, and increased sweating [10-12]. Given the immediate threat to safety, in the event of a violation of vertical stability, it is believed that the autonomic nervous system (ANS) helps coordinating compensatory postural adjustments. For instance, a study by Maki & Whitelaw showed that during postural instability there was an increase in the activity of the sympathetic

ANS, which suggested the hypothetical participation of the ANS in postural control [13-16].

The interaction of sympathetic and parasympathetic nerves leads to small differences in the RR interval of successive heartbeats, thereby causing cardiovascular variability known as heart rate variability (HRV) [17, 18]. Some diseases or other factors cause changes in the balance of the cardiac sympathetic and vagus nerves, which can lead to changes in heart rate, HRV, and cardiovascular dysfunction [19, 20].

The *objective* of our study was to establish the relationship between postural balance and HRV in elderly women with the falls syndrome.

Material and Methods

Study participants

The study was conducted on 120 women aged 60-74 years. The study group included women with the falls syndrome who experienced two or more falls during the year, while the control group consisted of women without postural balance disorders.

The exclusion criteria were as follows: acute cerebral circulatory disorders, traumatic brain injuries, acute myocardial infarction, chronic heart failure, cardiac arrhythmias above grade 3 *sensu* M. Ryan and B. Lown, psychiatric diseases, signs of senile dementia, and inability to perform all required tests without external help (*Table 1*).

Postural balance assessment

For a comprehensive assessment of the functional state of postural balance, we used the method of stabilometry with the computer stabilometric complex, *NeuroCom SMART Balance Master®*, Natus Medical, USA. First, all participants of the experiment were shown videos explaining in detail the stages and algorithms of performing the following five functional tests. Each study subject was required to complete each test three times:

(1) Sit to Stand test allows quantifying the ability of a person to change the body position from sitting to standing. The measured parameters are weight transfer time (s), rising index (cm/s), and sway velocity (cm/s).

(2) Cross Walk test allows quantifying the gait indicators when the subject walks from the beginning of the platform to its end. The measured parameters are step width (cm), step length (cm), and speed (cm/s).

(3) Tandem Walk test allows quantifying the gait indicators when the subject walks from the beginning to the end of the stabilometric platform trying to match the heel of one foot with the toe of another foot as precisely as possible. The measured parameters are step width (cm), walking speed (cm/s), and endpoint sway velocity (cm/s).

Table 1. Characteristics of women with and without falls syndrome, mean (Q1-Q3)

Characteristics	*Study group (n=60)*	*Control group (n=60)*	*P*
Age (YO)	65.0 (62.0-69.8)	65.0 (62.0-68.0)	0.607
Height (cm)	157.5 (152.3-160.8)	158.0 (155.0-161.8)	0.181
Body weight (kg)	71.9 (64.0-81.8)	72.8 (66.2 -79.6)	0.908
BMI (kg/m2)	29.3 (26.1-32.9)	29.3 (26.2-31.8)	0.652
Falls (annual number)	1.3 (1.1-1.5)	-	-

(4) Step Quick Turn test allows determining the characteristics of the rotation efficacy after the subject takes two steps forward, quickly turns 180° and returns to the starting point. The measured parameters are times for the left and right turns (s), and sway velocities during turning left and right (cm/s).

(5) Step Up and Over test allows quantifying the gait control when stepping over obstacles on a 20 cm high stabilometric platform. The measured parameters are left and right lift-up indices (cm/s), movement times left and right (s), and impact indices left and right (cm/s).

Mean values were calculated for all measured variables.

Assessing the state of autonomic nervous system

The study of HRV was carried out via cardiointervalography by the *VNS-Spectrum* computer appliance (Neurosoft, Russia). ECG was recorded using general methodology (5-min recording after 10-min rest in the lying position).

HRV was assessed in terms of three groups of indicators:

(1) Statistical: standard deviation of the values of normal RR intervals (SDNN, ms), an integral indicator characterizing the variability of the heart rhythm in its entirety; square root of mean squares of the differences between the values of successive pairs of NN intervals (RMSSD, ms); proportion of consecutive NN intervals with the difference exceeding 50 ms (pNN50); degree of parasympathetic control predominance, %; and coefficient of variation (CV, %);

(2) Spectral: total power of the spectrum (TP, ms2) characterizing the overall variability of the rhythm, determined by the combined effect of the sympathetic and parasympathetic parts of the ANS; balance of sympathetic and parasympathetic effects (LF/HF, cu); relative power of very low frequency oscillations (VLF, %) characterizing specific contribution of very-low-frequency oscillations to the total power of the spectrum; relative power of low frequency oscillations (LF, %) characterizing specific contribution of low-frequency oscillations to the total power of the spectrum; and relative power of high–frequency oscillations (HF, %) characterizing specific contribution of high-frequency oscillations to the total power of the spectrum.

(3) HRV metrics *sensu* R.M. Baevsky: autonomic rhythm indicator (ARI, cu) demonstrating the presence of parasympathetic shifts in the autonomic balance; index of autonomic equilibrium (IAE, cu) reflecting the ratio of sympathetic and parasympathetic ANS activity; indicator of the adequacy of regulatory processes (IARP, cu) characterizing the correspondence of the sympathetic ANS contribution and the leading level of the sinus node functioning; and stress index (SI, cu) characterizing the degree of centralization of heart rhythm control [21].

Statistical data processing

The analyses were performed using IBM® SPSS® Statistics version 23.0 (USA). The evaluation of the intersystem interaction of HRV and postural balance indicators was performed using the Spearman correlation analysis of collected data. The statistical significance level was assumed at $p \leq 0.05$. A qualitative assessment of the association strength between the obtained data was carried out using the Cheddock scale criteria: at $r=0$, we stated no correlation whatsoever; at $0<r<0.3$, we regarded correlation as

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negligible; at 0.3≤r<0.5, we considered it moderate; at 0.5≤r<0.7, we considered it noticeable; at 0.7≤r<0.9, we classified it as strong; at 0.9≤r<1, we regarded it very strong; at r=1, we stated functional correlation. Direct correlation of indicators was noted at r>0; inverse correlation was determined at r<0.

Results

The compared groups exhibited no significant differences in age (p=0.607), height (p=0.181), body weight (p=0.908), and body mass index (p=0.652).

Correlation analysis established a number of associations in both studied groups. We discovered that the matrix of intersystem correlations between the indicators of postural balance and HRV in elderly women with the falls syndrome was characterized by just a few statistically significant correlations, 19 out of 304 possible (6.25%). In the control group, the number of significant correlations was 33 out of 304 possible (10.85%) (*Table 2*).

In elderly women with the falls syndrome, correlations with HRV indicators were noted for the following tests: Sit to Stand, Tandem Walk, and Step Up and Over. E.g., the following HRV indicators statistically significantly correlated with the time of body weight transfer in the Sit to Stand test: HF% (r=0.262), VLF% (r=-0.291), and ARI (r=-0.257). TP (r=-0.279) and LF (r=-0.261) were significantly associated with the walking speed of the Tandem Walk test, while LF% (r=0.285) correlated with endpoint sway velocity. The largest number of correlations was noted for the Step Up and Over test. As a result of this test, we established significant associations between the impact index of the left foot and SDNN (r=0.262), RMSSD (r=0.333), HF (r=0.352), VL/HF (r=-0.277), VLF% (r=-0.399), HF% (r=0.401) and ARI (r=-0.270); as well as between the impact index of the right foot and RMSSD (r=0.282), pNN50 (r=0.267), HF (r=0.323), VL/HF (r=-0.380), VLF% (r=-0.352), and HF% (r=0.397) (*Table 3*).

In the control group, correlations with HRV indicators were noted only in the Step Quick Turn test. For instance, the time of performing a turn when moving with a left foot correlated with the following HRV indicators: SDNN (r=-0.271), TP (r=-0.345), VLF (r=-0.307), HF (r=-0.308), ARI (r=0.294), IAPR (r=0.303), and SI (r=0.308); turning time when moving from the right foot correlated with VLF (r=-0.266), ARI (r=0.257), and IARP (r=0.260). The sway of the center of gravity when moving from the left foot was associated with SDNN (r=-0.364), RMSSD (r=-0.348), CV (r=-0.272), TP (r=-0.463), VLF (r=-0.409), LF (r= -0.397), HF (r=-0.436), VLF% (r=0.289), ARI (r=0.365), IAPR (r=0.448), and SI (r=0.397). The sway of the center of gravity when moving from the right foot was associated with SDNN (r=-0.320), RMSSD (r=-0.295), CV (r=-0.265), TP (r=-0.392), VLF (r=-0.375), LF (r=-0.326), HF (r=-0.366), HF% (r=-0.260), ARI (r=0.352), IAE (r=0.292), IAPR (r=0.324), and SI (r=0.358).

Discussion

As a result of the analysis of the collected data, it can be stated that we observed a reduction in the number of significant associations of physiological systems in charge of maintaining the postural balance with the ANS in the elderly women with the falls syndrome vs. those without it (the control group).

We also established that the group of women with postural balance disorders was characterized by the presence of new connections of HRV indicators with indicators of performance quality of complex motor acts and strength indicators of postural balance.

The largest number of correlations between postural balance and ANS indicators was noted in the Step Up and Over test in the study group and in Step Quick Turn test in the control group.

As a result of a study conducted in women with the falls syndrome, we confirmed the existence of the relationships between the speed indicators of the proposed motor acts of the Tandem Walk and Step Up and Over tests with the indicators characterizing specific contributions of high-frequency and very low-frequency oscillations to the total power of the spectrum, adrenergic influence on rhythm variability, general rhythm variability determined by the joint effect by the sympathetic and parasympathetic ANS, as well as with the indicators reflecting the contribution of the sympathetic ANS to rhythm variability. A direct connection was discovered between the accuracy of performing a specific motor act and HRV indicators characterizing the specific contribution of low-frequency oscillations to the total power of the spectrum [2, 4, 6].

Table 2. Spearman correlation coefficient matrix for women with falls syndrome

HRV indicators	*Postural balance indicators* Weight transfer time	Tandem Walk speed	Tandem Walk endpoint sway velocity	Impact index left	Impact index right
SDNN				0.262*	
RMSSD				0.333**	0.282*
pNN50					0.267*
TP		-0.279*			
VLF					
LF		-0.261*			
HF				0.352**	0.323*
LF/HF				-0.277*	-0.380**
VLF%	-0.291*			-0.399**	-0.352**
LF%			0.285*		
HF%	0.262*			0.401**	0.397**
ARI	-0.257*			-0.270*	

* p<0.05; ** p<0.01 vs. the control group.

Table 3. Spearman correlation coefficient matrix for the control group

HRV indicators	*Postural balance indicators* *Left turn time*	*Right turn time*	*Sway turning left*	*Sway turning right*
SDNN	-0.271*		-0.364**	-0.320*
RMSSD			-0.348**	-0.295*
CV			-0.272*	-0.265*
TP	-0.345**		-0.463**	-0.392**
VLF	-0.307*	-0.266*	-0.409**	-0.375**
LF			-0.397**	-0.326*
HF	-0.308*		-0.436**	-0.366**
VLF%			0.289*	
HF%				-0.260*
ARI	0.294*	0.257*	0.365**	0.352**
IAE		0.260*		0.292*
IAPR	0.303*		0.448**	0.324*
SI	0.308*		0.397**	0.358**

* p<0.05; ** p<0.01 vs. the control group.

The sympathetic ANS is involved in the control of excitation, which leads to the activation of the body's physiological resources to meet increased metabolic demands in difficult situations. The sympathetic system is usually constantly active; the degree of activity changes dynamically over time. However, during emergency situations or threats, the activity of the sympathetic ANS reaches a maximum [2, 8, 16].

When performing tests that determine the strength indicators of postural balance when stepping over an obstacle, the sympathetic nervous system is activated, which was expressed in the presence of a direct relationship between indicators of muscle effort when moving the left or right leg with indicators characterizing HRV in general, determining the increased contributions of sympathetic control of the heart rhythm and the power of high-frequency oscillations, as well as the specific contribution of high-frequency oscillations to the total power of the spectrum. Also, it was expressed in the inverse correlation of muscle effort indicators when moving from the left and right legs with indicators that determine the specific contribution of very low-frequency oscillations to the overall power of the spectrum and demonstrate the degree of predominance of the parasympathetic control and, accordingly, its reduction [11, 14].

In the control group of women, we revealed a direct correlation between the accuracy of performing a complex motor act in the Step Quick Turn test and HRV indicators in charge of the adrenergic effect on rhythm variability and specific contribution of very low-frequency oscillations to the total power of the spectrum. We also established the feedback with indicators characterizing HRV as a whole, suprasegmental effects on rhythm variability, and overall rhythm variability, determined by the combined influence of the sympathetic and parasympathetic ANS.

Feedback was also found in tests designed to identify the time performance indicators of the proposed complex motor acts with indicators characterizing the overall rhythm variability, determined by the joint influences of the sympathetic and parasympathetic ANS; as well as in tests determining suprasegmental influences on rhythm variability and reflecting the contribution of the parasympathetic ANS to rhythm variability [11].

Conclusion

This article presented the features of the relationship between postural balance indicators and HRV in elderly women with the falls syndrome characterized by a worse coordination of intersystem interactions of HRV indicators with indicators of the performance quality of complex motor acts and power indicators of postural balance, as compared with the elderly women without falls syndrome. The largest number of correlations between the studied indicators was found in the Step Up and Over test for women with falls syndrome and in the Step Quick Turn test for women without it.

Limitations

Our study has a number of limitations that should be disclosed and discussed. Taking into account that it was conducted in the region of the Arctic Zone of the Russian Federation and solely elderly women participated in it, it is necessary to further expand the geography of prospective study participants by including individuals living in milder climatic conditions, and to evaluate these features in other age groups of both women and men.

Conflict of interest

Authors have no conflicts of interest to disclose.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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