Original article

Characterizing the state of heart rate autonomic regulation and EEG in elderly women with falls syndrome

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Abstract: *Objective* — The goal of our study was to evaluate the contribution of the central and autonomic nervous systems to the maintenance of postural balance in the elderly.
Material and Methods — This study included 120 healthy women 60-74 YO living in the community. They were distributed among two subgroups: (1) fallers (n=60) and (2) non-fallers (n=60). Fallers had falls in the past 12 months, while non-fallers had none. Walk tests were performed using *Balance Master*® posturography machine (NeuroCom, Natus, USA). The state of the central nervous system was assessed by *Geodesic 300* EEG system (GSN; Electrical Geodesics, Inc.; Eugene, OR, USA). The state of the autonomic nervous system was assessed by the *VNS-Spectrum* (Neurosoft, Russia) via cardiointervalography.
Results — In Sit to Stand test, the postural sway velocity was higher (p=0.047) and the walking speed (p=0.008) in Tandem Walk test was lower in fallers, compared with non-fallers. The results of the Step Quick Turn test showed that the movement times of the left and right legs were longer for the fallers vs. non-fallers (p=0.044 and p=0.036, respectively), and postural sway values during turning left or right were higher in fallers as well (p=0.001 and p=0.003, correspondingly). At the same time, Step Up and Over test revealed that lift-up index values were higher in fallers vs. non-fallers (p=0.016). There were no statistically significant differences between the groups in the state of the autonomic nervous system. The absolute spectral power of the EEG was lower in the frontal region of the right hemisphere in the alpha and beta EEG bands in the study group, compared with the control.
Conclusion — A deterioration in the quality of performing complex motor actions and a decrease in postural control in elderly women with falls syndrome were which may have caused their postural instability. Our results confirmed the need for early assessment of the dynamic components of postural control to prevent the development of falls as a geriatric syndrome.

Keywords: mobility, walking, falls syndrome, women, autonomic nervous system, EEG, elderly.

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Introduction

The ability to maintain postural balance is crucial for most types of activity in everyday life [1-3]. Balance or postural balance describes the ability of a person to keep the body in an upright position, while walking or performing other motor actions, or at rest [4, 5]. Ensuring postural stability is a complex skill that depends on the coordination of musculoskeletal and sensory systems, implemented under the control of the nervous system [6, 7].

In elderly people, the full functioning of the postural management system is also an important factor that allows them pursuing an active lifestyle and maintaining their social independence. At the same time, age-related changes in postural balance are the main cause of falls in the elderly [8]. E.g., the general prevalence of *falls syndrome* of various etiologies for the elderly is 15-36%, while exceeding 40% in senile people [9].

The health status of elderly people largely depends on the ability of the autonomic nervous system (ANS) to control the body, as well as on maintaining homeostasis, which ensures optimal activity patterns [10].

It is demonstrated that in humans, the muscular system, along with central nervous system and ANS, have great compensatory capabilities; hence, postural reprogramming ensues gradually during prolonged overloads. However, when, as a result of exogenous and endogenous factors, adaptive mechanisms cannot compensate for postural equilibrium, a *postural deficiency syndrome* occurs, which, in turn, leads to an imbalance of the ANS [11].

According to the concept of visceral motor reflex connections, disorders of the musculoskeletal system are interconnected with the state of nonspecific brain structures, a clinical reflection of which is the syndrome of autonomic dystonia. According to some studies, postural muscular dystonic disorders should be assessed in conjunction with the functional state of ANS and cardiovascular system [12].

Given the immediate safety hazard, in the event of vertical stability impairment, the ANS is believed to facilitate the coordination of compensatory postural responses. For instance, the study by O'Brien et al. demonstrated that postural instability leads to an increase in the activity of the sympathetic division of the ANS, which implies hypothetical involvement of the ANS in postural control [13].

It was also shown that people at risk of developing falls syndrome may have an unusually high level of ANS activation threshold, which could lead to inadequacy of postural reactions. It is known that autonomic dysfunction is associated with certain forms of dementia, and people with dementia have extremely high incidence of falls [14]. Accordingly, a decrease in autonomic (sympathetic) reactivity can also contribute to the ineffectiveness of the implementation of postural reactions. Recent studies pointed to the contribution of the ANS to the maintenance of postural balance. E.g., the data of some studies demonstrated that the ANS can contribute to a coordinated compensatory postural response and to maintaining a proper postural balance [10, 15].

Also, one of the informative methods for studying the neurophysiological mechanisms of human brain activity is the mathematical analysis of electroencephalograms (EEG), in particular, EEG spectral analysis and EEG coherence analysis that reflect the measure of the functional connection between regions of the cerebral cortex. This approach is widely used in numerous studies aimed at studying the motor, cognitive, and emotional activity of a person in normal and pathological conditions of the brain, and may be promising for studying the neurophysiological mechanisms of the postural control system.

The objective of our study was to evaluate the contribution of the ANS to the maintenance of postural balance in elderly people.

Material and Methods

Study participants

The study enrolled 120 women aged 60-74 YO born and permanently residing in the European North of the Russian Federation.

The exclusion criteria were: elderly women registered in outpatient psychiatric institutions (neuropsychiatric dispensaries, etc.), stroke, signs of a significant reduction in higher cognitive functions (senile dementia), traumatic brain injuries, acute disorders of cerebral circulation, chronic heart failure above the functional class 1 sensu the classification by New York Heart Association (NYHA), acute myocardial infarctions, cardiac arrhythmias above the class 3 sensu Ryan and Lown [16].

The participants were informed of the goal and potential risks of the study and signed written informed consent in accordance with the outlines of the Declaration of Helsinki by the World Medical Association and Ethical Principles for Medical Research Involving Human Subjects.

Falls syndrome assessment

The study of the prevalence of the falls syndrome among elderly women was carried out on the basis of a survey of subjects regarding the occurrence of falls during the last 12 months prior to the survey. Thus, two groups were formed. The study group (subjects with falls syndrome) encompassing elderly women with 1 or more falls during the calendar year preceding the day of the study. In this case, a fall is understood as an event that leads to an unintentional presence of a woman on the ground or on a floor, or other surface located below her initial position [17]. The control group included elderly women without falls. The sizes of both formed groups were equal: each included 60 elderly women.

Anthropometric measurements

The anthropometric measurements were carried out to determine the length and body weight of the subjects, and the body mass index was calculated using standard algorithm.

Postural balance assessment

The assessment of the postural balance was carried out via the computerized dynamic posturography using the hardware and software complex of Balance Master®, NeuroCom, Natus, USA. To quantify the postural balance in the study, each subject underwent 5 tests: Sit to Stand, Walk Across, Tandem Walk, Step Quick Turn, Step Up and Over [18]. First, all participants of the experiment were shown videos explaining in detail the stages and mechanisms of performing these functional tests.

Measuring brain neuronal activity

The EEG was recorded for neural activity assessment. Resting-state EEG was recorded with a 128-channel high-density EEG *Geodetic System 300* (GSN; Electrical Geodesics, Inc.; Eugene, OR, USA) for 5 minutes. Throughout the EEG recording, participants sat comfortably with their eyes closed in a dark and soundproof room. For EEG analysis, data were obtained using an international 10-20 system. The data were filtered. Additional low-pass (100 Hz) and high-pass (1 Hz) EEG processing began with filtering for linear noise attenuation using a 55-65 Hz notch filter, while the high-frequency filter was set to 0.1 Hz, and the low-frequency filter was set to 30 Hz. Areas without artifacts were selected for spectral power analysis of delta (0.5-3.5 Hz), theta (3.5-7 Hz), alpha 1 (7-11 Hz), alpha 2 (11-13 Hz), beta 1 (13-16.5 Hz), and beta 2 (16.5-20 Hz) EEG bands.

Assessing the state of autonomic nervous system

The state of the ANS was assessed by the comprehensive device, *VNS-Spectrum* (Neurosoft, Russia) via cardiointervalography. When developing the study protocol, we complied with the recommendations by European Society of Cardiology, as well as North American Society of Pacing and Electrophysiology, according to which the duration of the study was 5 minutes, the subject was in a horizontal position after a preliminary rest for 10 minutes [18]. HRV was evaluated according to three groups of indicators [18]:

- Statistical: SDNN index (ms), RMSSD (ms), pNN50 (%), CV (%);
- Spectral: TP (ms^2), LF/HF (CU), VLF (%), LF (%), HF (%).
- Those related to HRV metrics sensu R.M. Baevsky: VEI (CU), IARP (CU), VRI (CU), IT (CU).

Table 1. Data on women with and without falls syndrome, mean (Q_1-Q_3)

Parameters	*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 mass (kg)	71.9 (64.0-81.8)	72.8 (66.2 -79.6)	0.908
BMI (kg/m^2)	29.3 (26.1-32.9)	29.3 (26.2-31.8)	0.652
Falls (annual number)	1.3 (1.1-1.5)	-	-

Table 2 Characteristics of postural balance in women with and without falls syndrome, ME (Q_1-Q_3)

Parameters	*Study group (n=60)*	*Control group (n=60)*	*P*
Sit to Stand test			
Weight transfer time (s)	0.4 (0.3-0.5)	0.4 (0.3-0.6)	0.256
Rising index (cm/s)	18 (13.0-24.0)	17.5 (14.0-20.0)	0.695
Sway velocity (cm/s)	3.9 (3.1-4.2)	3.8 (2.9-4.1)*	0.047
Walk Across test			
Step width (cm)	12.9 (10.8-15.0)	13.1 (10.9-15.4)	0.508
Step length (cm)	56.4 (49.6-62.1)	58.7 (54.7-62.4)	0.224
Speed (cm/s)	84.4 (74.0-93.9)	86.3 (78.1-96.5)	0.120
Tandem Walk test			
Step width (cm)	7.90 (6,5-10.4)	7.65 (6.9-8.9)	0.395
Speed (cm/s)	27.3 (22.6-35.2)	32.2 (25.6-35.8)**	0.008
Endpoint sway (cm/s)	5.60 (4.6-7.6)	5.3 (4.1-6.9)	0,201
Step Quick Turn test			
Time left leg (s)	1.7 (1.2-2.3)	1.4 (0.9-2.1)*	0.044
Time right leg (s)	1.5 (1.2-2.0)	1.2 (0.9-1.7)*	0.036
Sway, left (cm/s)	30.6 (25.3-18.3	24.4 (18.2-31.4)***	0.001
Sway, right (cm/s)	30.3 (25.4-36.3)	25.0 (18.1-37.8)**	0.003
Step Up and Over test			
Lift-up index, left (cm/s)	38.5 (32.0-45.7)	41.0 (35.2-49.7)	0.103
Lift-up index, right (cm/s)	39.0 (33.0-46.0)	43.0 (37.2-52.7)**	0.016
Movement time, left (s)	1.5 (1.4-1.72)	1.5 (1.27-1.7)	0.163
Movement time, right (s)	1.52 (1.3-1.7)	1.5 (1.2-1.6)	0.137
Impact index, left (cm/s)	61.00 (46.0-81.2)	61.0 (45.2-74.7)	0.594
Impact index, right (cm/s)	57.0 (45.0-75.0)	55.5 (45.0-69.5)	0.700

* *p*<0.05; ** *p*<0.01; *** *p*<0.001 vs. the control group.

Table 3 Parameters of the state of the autonomic nervous system in women with and without falls syndrome, ME (Q_1-Q_3)

Parameters	*Study group (n=60)*	*Control group (n=60)*	*P*
Statistical parameters			
SDNN, (ms)	46.5 (28.2-94.5)	42.5 (26.2-104.5)	0.717
RMSSD (ms)	45.0 (22.2-89.7)	37.5 (25.2-98.7)	0.826
pNN50 (%)	4.9 (1.6-10.4)	4.7 (2.3-10.5)	0.352
CV (%)	5.6 (3.4-10.2)	4.8 (2.8-10.6)	0.761
Spectral parameters			
TP (ms^2)	1720.5 (695.2-5236.1)	1334.3 (571.3-4587.0)	0.378
LF/HF (CU)	0.6 (0.4-1.1)	0.58 (0.45-0.82)	0.264
VLF (%)	23.2 (14.7-53.8)	27.5 (15.4-41.8)	0.838
LF (%)	25.9 (20.5-30.1)	26.2 (19.6-29.9)	0.941
HF (%)	45.0 (23.4-55.6)	48.3 (32.8-56.6)	0.372
Heart rate metrics parameters sensu R.M. Baevsky			
VEI (CU)	133.7 (54.8-303.6)	159.1 (61.3-364.2)	0.702
IARP (CU)	65.8 (50.8-85.4)	65.6 (50.5-83.9)	0.467
VRI (CU)	2.7 (1.2-5.6)	3.6 (1.1-6.6)	0.522
IT(CU)	80.3 (29.8-181.5)	100.6 (30.7-204.1)	0.803

Statistical data processing

The analyses were performed using IBM® SPSS® Statistics version 23.0 (USA). The normal distribution of the measured variables was assessed using the Shapiro-Wilk test. Due to the fact that the distribution of some data was different from normal, the results are presented in the form of median (Me) and interquartile range (Q1-Q3). Pairwise comparisons of quantitative data were carried out using the Mann-Whitney U criterion. For qualitative data, the $\chi 2$ criterion was used. Statistical significance was assumed at $p<0.05$.

Results

The groups were similar in terms of age: in the study group, mean age was 65.0 (62.0-69.8) years, and in the control group, it was 65.0 (62.0-68.0), (p=0.607). Same was true about median values of body length (p=0.181), body mass (p=0.908), and body mass index (p=0.652) in the compared groups (*Table* 1).

Characteristics of postural balance in women with and without postural stability are presented in *Table* 2. No significant differences between the groups were implied by the results of Walk Across test, Sit to Stand test, weight transfer time and rising index (*Table* 2).

Also, we did not observe significant differences in movement time and impact index in Step Up and Over test, as well as in step width and endpoint sway in the Tandem Walk test.

The sway velocity in Sit to Stand test was higher in the study group vs. the control group (*p*=0.047).

The walking speed in Tandem Walk test was lower in the study group vs. the control group (*p*=0.008). The results of Step Quick Turn test suggested that in study group vs. the control, movement times with left and right legs were longer (*p*=0.044 and *p*=0.036, respectively) and sway values during turning left or right were higher (*p*=0.001 and *p*=0.003, correspondingly). At the same time, Step Up and Over test revealed that lift-up index values were higher in the study group (*p*=0.016).

There were no statistically significant differences between the groups in the state of the ANS either by statistical, or spectral, or else heart rate metrics parameters sensu R.M. Baevsky (*Table* 3).

The EEG data analysis revealed significant differences in the absolute spectral power and amplitude values in alpha and beta bands of the right frontal region in women of study group. E.g., women of study group had significantly lower values of the spectral power of alpha-1 (Me=2.078 µV2; U=233.0; Z=-2.100; p=0.036) and alpha-2 (Me=0.988 µV2; U=225 .0; Z=-2.242; p=0.025) bands in the frontal region of the right hemisphere (F4). The study group also had a lower spectral power of the beta-1 band (Me=0.922 µV2; U=215.00; Z=-2.420; p=0.016) in the frontal region (F4) of the right hemisphere, compared with the control group (Me=2.523 µV2).

We established that study group subjects were characterized by a lower amplitude of the beta band in the anterior frontal (Fp2, Me=0.323 µV; U=247.0; Z=-2.03; p=0.042), frontal (F4, Me =0.278 µV; U=233.0; Z=-2.29; p=0.022), and central (C4, Me=0.263 µV; U=246.5; Z=-2.04; p=0.041) regions of the right hemisphere, vs. the control group. Coherence values of the alpha band between the anterior frontal and frontal (Fp2-F8) regions both in the right (M=0.81±0.09; t=1.95; p=0.05) and in the left hemisphere (M= 0.82±0.14; t=2.05; p=0.04) were significantly lower in individuals with falls syndrome, compared with the coherence values of the right and left hemispheres in the control group (M=0.97±0.07; M= 0.95±0.08, respectively).

Discussion

In the course of our study, we discovered statistically significant differences in postural balance indicators between elderly women of the study group and control group, signifying deterioration in the quality of performing complex motor actions and a decrease in postural control of elderly women with falls syndrome.

It is believed that standing up from a seated position is the most frequently performed component of everyday life and is a necessary condition for functional mobility [8; 16]. Standing up from a seated position is accomplished by the coordinated movement of the segments so that it moves forward and upward from a large, stable support base to a smaller, less stable support base [20]. The success of standing up to maintain stability and prevent falls depends on sufficient momentum to achieve an upright posture, generated by muscular activity, and on the state of postural balance. As a result of the process of standing up, the position of the body segments in space changes, followed by a shift in the center of the body gravity. With age, the proportion of people experiencing difficulties in performing this type of locomotion increases significantly, which is primarily associated with age-related changes in the muscle and articular components of the musculoskeletal system [21]. Thus, the observed differences in indicators characterizing the features of maintaining a vertical posture at the time of standing up may indicate a small contribution of the musculoskeletal system pathology of the lower limbs to the development of the syndrome of falls with a significant influence of neurophysiological mechanisms responsible for maintaining postural balance.

Currently, this test has found wide application for screening patients for the detection of various neurological and vestibular disorders. Among its advantages, we can single out the ease of implementation and the duration of use in clinical practice, which helped accumulating a significant number of results. D.V. Skvortsov's study also indicated that this test is quite informative for diagnosing the falls syndrome [4]. Similar results demonstrating the significance of this test in the diagnosis of falls syndrome were obtained in another study as well [22]. Thus, a decrease in walking speed as a result of performing this test in elderly women with falls syndrome can be interpreted as a sign of deterioration in postural balance control.

Turning is a difficult task, requiring a change in the direction of the center of gravity without compromising the stability of the body's position in space. The quality of this test is significantly affected by the preservation of the functions of the visual and vestibular analyzers [20]. A decrease in the quality of afferent information coming from these analyzers is a significant predictor of the formation of a sedentary lifestyle and a decrease in mobility. Consequently, the decrease in the quality of the Step Quick Turn test can be considered as an example of the deterioration in the performance of complex motor actions in elderly women with falls syndrome. Changes in the parameters of this test in the elderly may also be the result of a decrease in their visual and vestibular information during balance control, along with ineffective stabilization of the head and trunk when walking, especially during sharp turns, and dysfunction of the musculoskeletal system. An increase in movement execution time may be associated with joint stiffness, bradykinesia, balance disorder, or an attempt to avoid discomfort [17, 20].

The research by Duarte and Zatsiorsky showed that when a person stands on one leg or with an inclined torso, the importance of afferent visual and vestibular information increases significantly. This is probably due to a decrease in the intensity of receiving proprioceptive information from mechanoreceptors on the soles of the feet [22]. At the same time, to maintain postural control, the system must rely more on visual and vestibular information for balance control. However, in our case, significant changes are noted only in the recovery index indicator. Therefore, it can be assumed that in elderly women with falls syndrome, in the course of performing complex motor actions, there is a deterioration in the implementation of neurophysiological control over the preservation of postural balance.

When analyzing indicators of HRV in the studied groups, we found no differences either in statistical indicators, or spectral indicators, or else in the indicators of heart rate metrics parameters sensu R.M. Baevsky (*Table* 3).

It is known that the ANS, in particular its sympathetic division, take part in the implementation of emergency responses of the body to external disturbing influences. Sympathetic responses to external influences are implemented via increased heart rate, vasoconstriction, redirection of blood flow to skeletal muscles, dilated pupils and increased sweating. Given the immediate safety hazard caused by changes in body position in space, the ANS is thought to promote a coordinated compensatory postural response. For instance, some studies noted that postural instability is accompanied by an increase in the sympathetic activity of the ANS, which implies ANS participation in postural control. Moreover, it was demonstrated that some individuals at risk of falling may have too high ANS activation threshold in threatening situations, such as unsteadiness. In turn, this could lead to inefficiency in the implementation of postural responses [13; 23]. The absence of significant differences among the studied sample in our study may be due to the fact that we examined a sample of an older age, and the expected differences in the activity of the ANS sympathetic division were offset by its physiological age-related changes.

To conduct a deeper analysis of the state of autonomic regulation, spectral analysis using fast Fourier transforms has now become widespread. It is well known that heart rate is highly variable. Spectral analysis makes it possible to split the total variance of the heart rate into the basic periodic rhythms that occur at different frequencies and reflect different physiological processes [18]. We did not establish the predominance of the influence of the sympathetic or parasympathetic division of the ANS on the rhythm variability, depending on the presence of the falls syndrome, which can also be explained by the predominance of age-related changes.

Analysis of HRV, according to R.N. Baevsky, allows assessing the state of the adaptive compensatory activity of the entire body. It has become widespread due to its simplicity, accessibility and high information content [10, 15, 23]. The results of this method for HRV assessment also did not reveal statistically significant differences between the group of elderly women and the comparison group.

Lower values of the spectral power of the alpha band probably indicate changes in the stem and brain diencephalic structures (atrophy of the hippocampus, decreased cerebral perfusion in the medial parts of the temporal lobes) [24]. Unlike low-frequency rhythms, which can have both cortical and subcortical origins, high-frequency rhythms are considered a cortical phenomenon. Their parameters are very individual and variable, which may imply a connection with the coding of acquired experience [25]. The low spectral power of the beta band in the frontal region may reflect dysfunction of the cortical structures of the frontal lobes (premotor, motor cortex) responsible for controlling motor actions. It is known that changes in EEG beta rhythms are associated both with the perception of simple stimuli and with the processes of integration of the components of complex stimuli, attention, and the level of wakefulness [26, 27].

Lower values of coherence between the frontal regions within both hemispheres may indicate possible dysfunctional changes at the cortical-subcortical level in the postural control system in women with falls syndrome.

Successful maintenance of a vertical posture with the leading role of the right hemisphere can be explained by its functional and morphological features. In the right vs. left hemisphere, a greater number of pathways, providing a greater connection between brain structures, was found [28]. Also, the right hemisphere has closer functional connections with the diencephalic structures of the brain. Since the main role in the process of maintaining a vertical posture belongs to the right hemisphere [29], the interhemispheric asymmetry, identified by us, could be a reflection of the dysfunction of the postural control system at the cortical-subcortical level.

Conclusion

Currently, the study of gait parameters in the elderly is increasingly used in gerontology and geriatrics, as it allows predicting the degree of deterioration in their mobility and the risk of falling. It was noted that rehabilitation programs aimed at maintaining the dynamic components of postural control, including in patients with postural instability, have a positive effect on reducing the risk of falls and subsequent preservation of mobility.

In the course of our study, we discovered statistically significant differences between elderly women of the study group and the control group in the performance of the following tests: Sit to Stand, Walk Across, Tandem Walk, Step Quick Turn, and Step Up and Over. These findings implied a deterioration in the quality of performing complex motor actions and a decrease in postural control in elderly women with the falls syndrome.

At the same time, we did not establish the presence of statistically significant differences between HRV indicators in the study group vs. the control group. In general, the absence of differences between them can be associated with a certain stability of HRV in elderly age, as well as with the presence of the cardiovascular system diseases and use of medications in the majority of examined women.

Analysis of the absolute spectral power of the EEG yielded its lower values in the frontal region of the right hemisphere in the alpha and beta bands in the main group vs. the control group. Also, the group with the syndrome of falls was characterized by the lower values of the beta band amplitude in the anterior frontal, frontal, and central regions of the right hemisphere. Our results implied the postural control system disorders in women of the study group, which could be the cause of their postural instability. Lower coherence values in the frontal regions of both hemispheres in women with falls syndrome may indicate the important involvement of these brain regions in the processing of spatial information, along with multisensory integration and the formation of the awareness of one’s own body position in space for controlling the upright posture.

Limitations

Our study had some limitations that should be disclosed and discussed. The study participants were exclusively women living in the North of European Russia. Thus, it is necessary to compare our results with similar studies conducted in other regions that are not subjected to extreme environmental conditions. All subjects in our study were relatively healthy, well-functioning 55-74 YO women (i.e., mostly elderly). Therefore, we recommend that an equivalent study be conducted on groups of middle-aged and senile women, and that our results be compared with the results of any prospective study conducted on both men and women.

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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